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PRELIMINARY ECONOMIC FEASIBILITY STUDY FOR GRAPHENE SYNTHESIS FROM KING GRASS AT LABORATORY SCALE

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Abstract: In the present study, a preliminary analysis of the technical and economic feasibility of using King Grass biomass for graphene material synthesis at a laboratory scale in Colombia was conducted. The performance results for biomass and cellulose production from King Grass using the peroxide-alkaline method and its chemical characterization indicate that the lignocellulosic chemical composition of the grass residue can be a viable and abundant raw material for graphene production. The technical-economic analysis for graphene synthesis using the procedure outlined in Patent ES2804948T3 at the laboratory scale reveals its feasibility, as the Net Present Value (NPV) is highly positive, and even in the initial study period, the initial investment can be recovered, resulting in a significantly positive internal rate of return. In this regard, an investment opportunity for graphene synthesis from King Grass at a laboratory scale is evident, with the potential for exploration at a pilot or industrial scale using more cost-effective and environmentally friendly methods.
Keywords: King Grass, Technical Economic Analysis, Graphene, Alkaline Peroxide.

INTRODUCTION

Since the discovery of graphene in 2004 and particularly in recent years, the number of scientific publications and patents has significantly increased, especially in the last five years (Lee et al., 2019). In general, graphene has been widely studied and reported as a two-dimensional material with intriguing physicochemical properties, including high thermal and electrical conductivity, large surface area, optical transparency, and mechanical strength, among others (Farías, Flores, Rosales, Sáenz, & López, 2017; Urcuyo Solórzano, Cordero Solano, & Gonzalez Flores, 2021). It has even been reported that graphene's strength is 200 times higher than structural steel, with hardness exceeding that of diamond (García, 2013; Pingale, Owhal, Katarkar, Belgamwar, & Rathore, 2021), in addition to its superior thermal and electrical properties compared to copper. Graphene has emerged as a highly attractive material for a wide range of applications across various fields, including technology, environment, medicine, and electronics, among others (Pachamango Bautista & Zapata Revoredo, 2018; Torkaman-Asadi & Kouchakzadeh, 2022; Urcuyo Solórzano et al., 2021). This enables the creation of products ranging from solid prosthetics for various body parts to extremely lightweight and exceptionally strong sports equipment. Furthermore, graphene can be easily combined with other materials, such as resins and polymers, resulting in compounds with specific and valuable properties. A notable example is its application in environmental remediation, where functionalized graphene is used to remove dyes, oils, organic pollutants, and heavy metals, among others (Thakkar & Malfatti, 2021; Wu, Hu, Qi, Hou, & Wei, 2020).

Every year, the number of publications and studies related to graphene production increases significantly, utilizing various physicochemical methods. Many of these approaches aim to enhance the experimental conditions of the original method proposed, known as the Hummers method (Lee et al., 2019; Saravanan et al., 2022; Jiabin Wang et al., 2021). This method has garnered attention due to its aggressive nature, high environmental impact, and elevated costs, involving substantial quantities of toxic chemical reagents, limiting its scalability and industrial applications. Over the past 15 years, several methods for graphene production have been developed, including mechanical and chemical exfoliation, as well as chemical reduction, among others (Pingale

et al., 2021)a 2-dimensional form of carbon, attracted significant attention in a wide range of applications such as energy storage, power generation, chemical sensors, composite materials owing to its unmatched physical and chemical properties. In this study, graphene powder was synthesized by ultrasonic-assisted electrochemical exfoliation of the graphite electrode from acidic bath. An external ultrasonic bath (ultrasonic frequency of 40 kHz and ultrasonic power of 180 W. These methods can be classified into two main categories: "TOP-DOWN" and "BOTTOM-UP" (Alam, Sharma, & Kumar, 2017; Yu, Zhang, Bulin, Li, & Xing, 2016; Yuan et al., 2017)graphene oxide (GO. The former group encompasses methods that start from larger molecular structures or aggregates to obtain graphene. Some notable examples include mechanical shear or ultrasonic exfoliation, as well as chemical exfoliation, involving the separation of graphite layers by the addition of a chemical compound (Alam et al., 2017; Yu et al., 2016)graphene oxide (GO. On the other hand, the latter group begins with smaller molecular structures, leading to graphene production, such as the reduction of graphite to graphene oxide and its subsequent oxidation to graphene, using the Hummers method.

Among the second group of graphene production methods is the chemical vapor deposition (CVD) method, where a catalytic metal layer is placed in a chamber that is heated in the presence of a hydrocarbon. When the hydrocarbon decomposes, carbon atoms are released and adhere to the catalytic metal. Although graphene production through the CVD method is one of the most widely used (Jiabin Wang et al., 2021) and offers superior yields, it unfortunately entails significant costs, especially due to energy consumption and the use of chemical reagents (Alam et al., 2017; Ali Roberto Ruiz Hernández, Adrián Gutiérrez Cruz, Daniela Luna, José Fernando Vega, Gerardo Patiño Guillén, 2021; Yuan et al., 2017). Furthermore, these methods require rigorous reaction conditions, high synthesis temperatures (around 1000°C), and long synthesis times, making them less attractive for large-scale production (Jiabin Wang et al., 2020; Jiabin Wang et al., 2021). Additionally, the transfer processes used to obtain graphene often affect the material's integrity and performance, leading to impurity formation or structural defects (Triana-Martínez, 2019; Zapana Mamani, 2021). On the other hand, the reduction or graphene oxide synthesis method involves the use of toxic reagents such as oxidizing agents, including concentrated sulfuric acid and potassium permanganate (Ramos, 2017), raising environmental concerns and limiting industrial viability.

In recent years, emerging methods for graphene production have focused on the use of biomass, capitalizing on its status as a widely available renewable resource (Athanasiou, Yannopoulos, & Ioannides, 2022). This perspective aims to reduce production costs and utilize environmentally friendly raw materials. Among the most widely used emerging methods are the use of microwave and ultrasound (Bukkitgar, Shetti, Raghava, Saleh, & Aminabhavi, 2020; Kumar, Sahoo, Joanni, & Kumar, 2022). Graphene production through these approaches is considered a favorable alternative as it involves simpler procedures, less toxic and cost-effective reagents, reduced production times, enhanced safety control, and high yields (Kumar et al., 2022; Pingale et al., 2021). These advantages reduce production costs, making graphene more appealing for industrial implementation.

In particular, in 2020, a patent was published proposing an alternative microwave process for synthesizing graphene from cellulose obtained from various biomass

sources as an economical raw material (L. Wang, Tang, Zhang, Zheng, & Baojiang, 2021), which reduces process costs. However, based on our literature review (**Figure 1**), despite the extensive amount of research related to graphene, more than 200,000 studies since 2010 in the ScienceDirect database, we have not identified technical and economic studies that fully support these claims. Additionally, as shown in **Figure 1**, research related to graphene has primarily focused on the study of synthesis methods and their application in the energy field. This contrasts with the lack of research directed towards technical and economic studies, financial feasibility analysis, or other related investigations. This research gap is relevant because, although it is evident that the economic viability of this technology has not yet been achieved, it is essential to understand this economic gap to identify the outstanding challenges and facilitate graphene's implementation, known as the material of the future.

Based on the above, this work proposes to conduct a preliminary study of the economic feasibility of using King Grass biomass for graphene material synthesis in Colombia at a laboratory scale, based on one of the experimental procedures indicated in Patent ES2804948T3 (L. Wang et al., 2021).

METHODOLOGY

RAW MATERIAL COLLECTION

The raw material consisted of cellulose obtained from purple "King Grass" biomass, for which a collection process was conducted through multiple sampling sessions in Guarne, Antioquia, Colombia (Alto de la Virgen, 6°19'25.1"N 75°27'26.2"W). Subsequently, manual removal of any materials other than the grass was performed, and the drying process was carried out in a convection oven at 60 °C for 48 hours. Following this, the material was ground using a blade mill, and the dried biomass powder was sieved using an ASTM No. 30 mesh (600 μm).

DELIGNIFICATION OF KING GRASS BIOMASS

Delignification of King Grass biomass was performed using a peroxide-alkaline process, which involved taking several batches of 20.00 grams of dried biomass powder and placing them in cylindrical glass reactors, approximately 15 cm in diameter and 7 cm in depth. The material was dispersed on the surface, and 160 mL of 10% hydrogen peroxide was added drop by drop, followed by adjusting the pH to 10 by adding drops of 2M NaOH (8 mL). The mixture was left to rest for 2 hours at room temperature to facilitate the delignification process. Subsequently, a wash with deionized water (1.6 liters) was carried out until reaching pH 7, followed by drying for 48 hours at 60 °C. The obtained biomass was then ground using an electric blade mill and sieved using an ASTM No. 30 mesh (600 μm).

CELLULOSE QUANTIFICATION AND IDENTIFICATION

Quantification of extractables and carbohydrates was performed by gravimetry using a Soxhlet extraction setup. Approximately 5 grams of each sample were wrapped in filter paper and connected to a flask with 250 mL of HPLC-grade distilled water in duplicate. The entire system was connected to a condenser and heated on a hot plate for 8 hours. The solvent was recovered through rotary evaporation, and the extractables were dried at 105 °C in an oven for 2 days until constant weight was achieved. The process was repeated with USP-grade ethanol. Following solid recovery, the chemical composition of the biomass was determined. Initially, the amount of extractables, both in water and

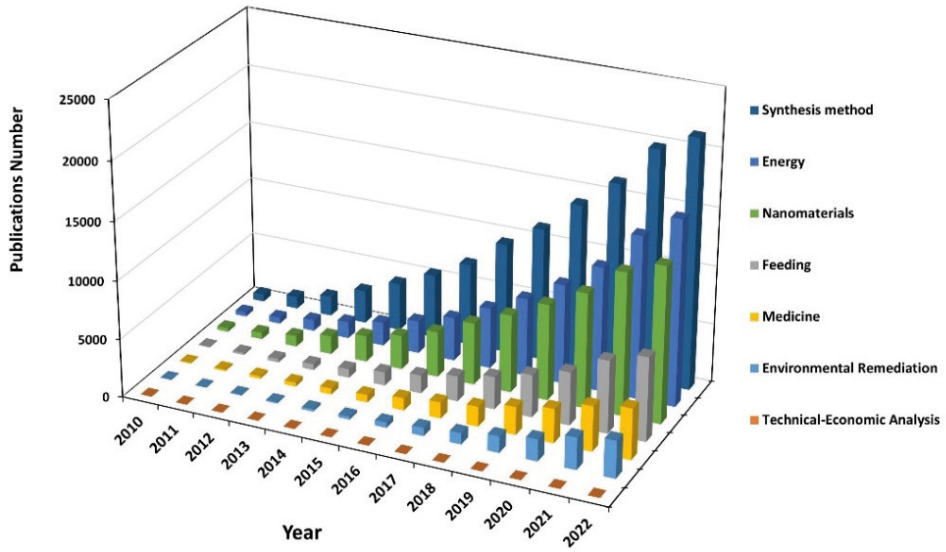

Figure 1. Published Graphene research by area of interest (Science Direct).

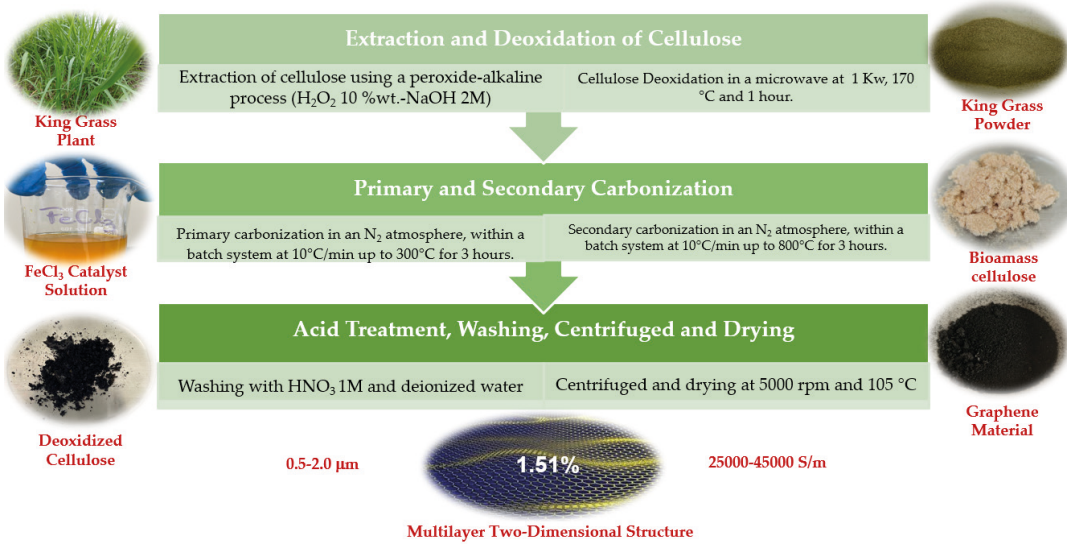

Figure 2. Experimental conditions for the selected Graphene synthesis route.

PROCESS											
Stage 1: Raw material conditioning				**Stage 2: Biomass delignification**				**Stage 3: Graphene production**			
Operational unit	**In (g)**	**Out (g)**	**Time (h)**	**Operational unit**	**In (g)**	**Out (g)**	**Time (h)**	**Operational unit**	**In (g)**	**Out (g)**	**Time (h)**
Separation and Disposal	152.7	149.6	0.5	Deslignification	20.00	20.00	2	Deoxygenation and microwave	9.56	8.13	1.5
Drying (oven)	149.6	23.85	48	Washing	20.00	11.66	0.5	Carbonization (thermal treatment)	8.13	2.53	4.5
Manual cutting	23.85	23.85	0.5	Drying	11.66	9.56	48	Acid treatment and washing	2.53	2.40	0.25
Grinding and Sieving	23.85	20.00	0.5	Grinding and Sieving	9.56	9.56	0.25	Drying	2.40	2.30	2

Table 1. Mass balance for graphene synthesis.

ethanol, was calculated using the NREL/TP -510-42619 standard. Lignin was determined based on the NREL/TP-510-42618 standard, and for the final chemical composition, holocellulose and cellulose were quantified using the ASTM D-1104 method.

A reference material of cellulose (Sigmacell Celluluse Type 101, Highly purified, Fibers, Marca Sigma – Aldrich) was used to compare the FTIR-ATR spectrum from the synthesized cellulose. Cellulose identification was performed by Fourier transform infrared spectra with attenuated total reflectance (FTIR/ATR) using a Shimadzu IR spectrophotometer (IRAffinity-1S) in the range of 400 - 4000 cm^{-1}.

GRAPHENE SYNTHESIS AND IDENTIFICATION

PREPARATION OF A CATALYTIC SOLUTION

0.6 g of the catalyst ($FeCl_3$) was added to 15 mL of deionized water (solvent-to-solute ratio of 1:25), and the mixture was magnetically stirred at 600 rpm for 30 minutes at room temperature to obtain a homogeneous catalytic solution.

PREPARATION OF THE PRECURSOR SOLUTION AND DEOXIDATION

The delignified biomass (3.75 g) was added to 15 mL of the previously prepared catalytic solution (solvent-to-solute ratio of 1:4), and then it was stirred with an overhead stirrer at 150 rpm for 30 minutes at room temperature to obtain the precursor solution. Subsequently, this mixture underwent deoxidation in a microwave digester for 60 minutes at a power of 1 kW and an approximate temperature of 170 °C.

THERMAL TREATMENT

The precursor obtained in the previous step was placed in a batch reactor, where the air atmosphere was replaced with nitrogen. The reactor was placed in a muffle to perform pre-carbonization from room temperature to 300 °C with a heating rate of 10 °C/min. Once this temperature was reached, it was held for 3 hours. Subsequently, the pre-carbonized product was pyrolyzed in the same reactor up to 1000 °C at 10 °C/min and held at this temperature for 3 hours to carry out the secondary carbonization treatment of the precursor.

ACID TREATMENT

Finally, the obtained material was washed with 1M HNO_3, centrifuged at 5000 rpm, then washed with deionized water, and dried at 105 °C for 2 hours to obtain graphene. **Figure 2** details the experimental conditions reported for graphene synthesis.

Commercial (Graphene Nano Powder 6-8 nm, CAS No. 7782-42-5) and synthesized graphene were characterized by UV-vis and Raman spectroscopy. Graphene samples were redispersed in N-methyl pyrrolidone (NMP) to form a 5 mg L^{-1} suspension, and then the suspension was centrifuged at 5000 rpm for 5 min. The clear upper solution was collected as the graphene solution for UV-vis spectroscopy measurements. The spectrum was recorded on a Shimadzu UV-spectrometer operating between 200 and 700 nm. Scattering experiments were performed using a Renishaw Raman Spectrometer with the excitation source at 632.81 nm. Raman spectra were recorded for 15 seconds, in a range from 600 cm^{-1} to 4000 cm^{-1}.

PRELIMINARY TECHNICAL-ECONOMIC ANALYSIS (TEA)

Tables 1 and **2** show the mass balance of the process based on the experimental conditions of the chosen graphene synthesis route and the selection of raw materials as the source of cellulose, equipment, and reagents used are detailed.

In order to assess the viability of employing "King Grass" biomass in graphene material synthesis, laboratory-scale graphene production was conducted using a "cradle-to-gate" system approach. For this purpose, one of the graphene synthesis procedures proposed in European Patent No. ES2804948T3 was chosen. Figure 3 illustrates the key stages addressed in this study: the collection and preparation of raw material (1), the conditioning of said raw material (2), the delignification of biomass (3), and, finally, graphene synthesis. To ascertain the average performance of the initial two stages, three batches were processed for each.

As the basis for calculation, reagent and raw material consumption, as well as yields obtained at the laboratory scale in each stage of the process, were used. For the monthly production projection, 26 batches were considered (including equipment downtime for loading, unloading, and cleaning). Each batch processed 153 grams of King Grass. Based on this information, **Table 2** summarizes the monthly reagent consumption and costs for the proposed graphene production system. The commercial values of the chemical substances were estimated based on various sources (Sigma-Aldrich, Merck, various websites, among others). Due to the preliminary nature of this study, **Table 3** assumes a conservative value, using an average of the values.

Raw material/ reagent	Unit	Monthly consumption	Monthly cost
King Grass	kg	4	-
H_2O_2 10%	L	4.2	$ 13'397,202
NaOH 2M	mL	208	$ 1'001,264
$FeCl_3$	g	15.6	$ 33,691
Nitrogen gas	m^3	1	$ 50,000
HNO_3 1M	L	1.15	$ 176,664
		Total	**$ 14'658,821**

Table 2. Monthly consumption and costs (COP) of reagents and raw material at the laboratory scale.

To obtain the graphene product, fixed investments are required, represented by various laboratory and computing equipment, including a convection oven, semi-industrial blade mill, ASTM sieves, electronic balance, muffle furnace, batch reactor, centrifuge, ultraturrax, microwave digester, and general glassware. Based on the costs of this laboratory-scale equipment, fixed investments were estimated at $197,720,639 COP. Additionally, the transportation of raw materials from Guarne to Bello, where the laboratory facilities are located (Medellín-Antioquia), is required, based on six monthly trips for a total of $360,000 (COP). Furthermore, according to the mass balance, the yield of raw material (King Grass) to graphene is 1.51%, with an annual production of 718 g.

Table 3 displays the estimated operating costs, encompassing expenses related to labor, water supply, electricity consumption, and monthly leases necessary for the operation of the process. The labor cost estimation is based on the current minimum wage in Colombia for the year 2023, considering the presence of highly qualified workers in the different experimental processes. Regarding the costs associated with water and energy, the average cost per cubic meter (m^3) and kilowatt-hour (kWh) in the city of Medellín (EPM, 2023) has been used as a reference (EPM, 2023).

In terms of leases, the average for

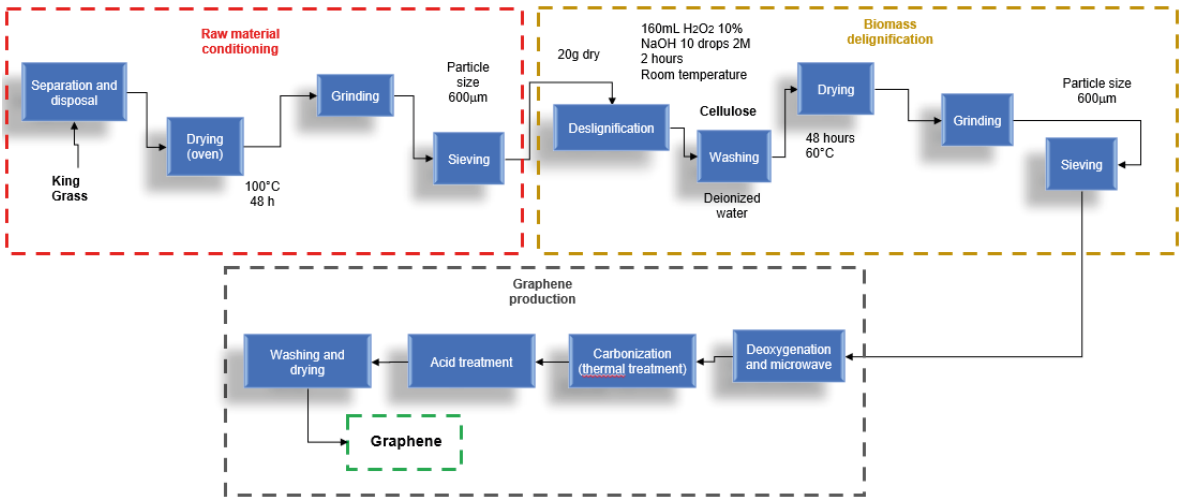

Figure 3. Process diagram for Graphene production.

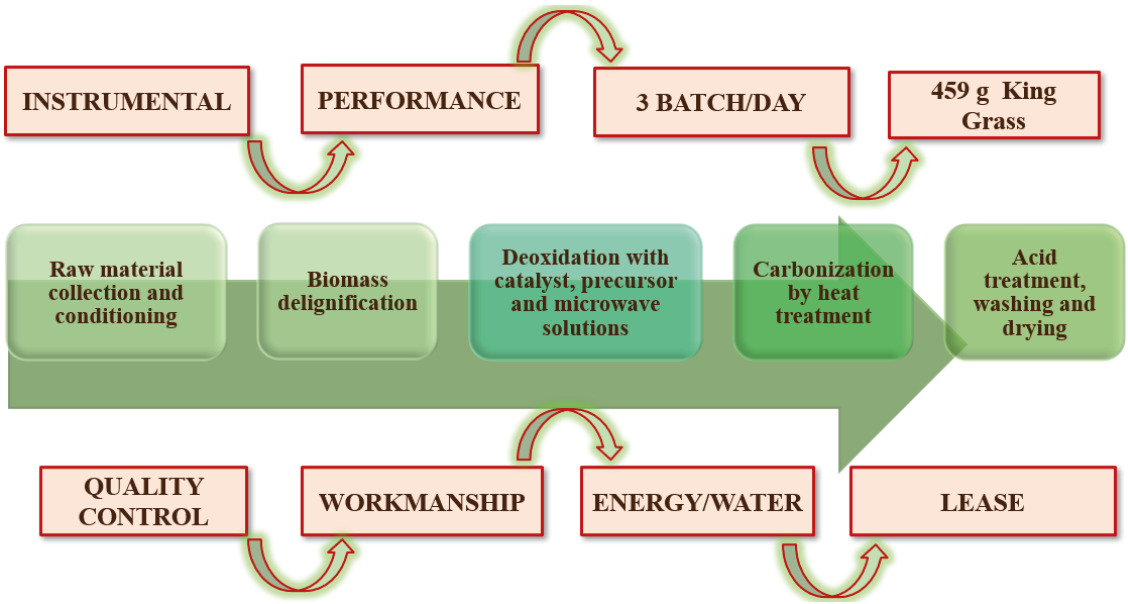

Figure 4. Stages of the Graphene synthesis process for the TEA.

Sample	Yield (%)	Moisture (%)	Extractables (%)			Carbohydrates (%)		
			Water	Ethanol	Lignin	Holocellulose	Hemicellulose	Cellulose
Raw, dry and milled grass biomass (RGB)	13.1	9.90	16.13	9.87	3.62	80.40	42.03	38.37
Delignified Grass biomass by alkaline peroxide (DGB)	47.8	7.65	0	0	0	94.0	28.24	65.8

Table 4. Carbohydrate content and yields for obtaining raw and delignified biomass.

commercial premises with areas ranging from 40 to 80 square meters in the city of Medellín has been considered. Additionally, costs related to technical services have been incorporated, including six monthly analyses of chemical composition, atomic absorption spectroscopy, Raman spectroscopy, proximate and ultimate analyses. The costs associated with these analyses have been established in accordance with the average values provided by certified laboratories.

Furthermore, the graphene selling price was estimated based on the estimated production volume. In general, the cost reported by the commercial house Sigma-Aldrich and Merck was used as a reference, with a value of $3,184 COP for each mg.

Description	Quantity	Unit	Unit cost	Total
Qualified workers	2	Salary	1'283,400	2'566,800
Water	0.043	m^3	4,059	175
Electricity	13.6	Kwh	563	7,637
Lease	1	N/A	400,000	400,000
Technical services	26	Analyses	361,104	9'388,704
Total				12'363,315

Table 3. Estimated operating costs for one month of production

For the project's feasibility analysis, some economic values were established, such as the average exchange rate of the dollar to Colombian pesos (COP) in September 2023 at 3,900 (COP) (DOLAR-COLOMBIA). To assess financial viability, the Internal Rate of Return (IRR), Net Present Value (NPV), and the Benefit-Cost Ratio (B/C Ratio) were evaluated. For this purpose, and in line with the typical financial behavior at the national level, the parameters were projected annually. In this regard, a 5% increase in costs was established based on the last five years of inflation in the country The opportunity rate was set at 9%, according to the National Planning Department, with a loan covering 50% of the initial investment and an interest rate of 12% for a 10-year projection. Furthermore, a consumer price index (CPI) of 3.50% and a 29% income tax rate were decreed (Redondo & Baez, 2015)multidrug resistanceassociated protein 1 (MRP1/ABCC1. At the same time, the salvage value was assumed to be the value of the investment in the purchase of equipment. Finally, since no liquidation value was estimated, a rescue value equal to the effective change flow that is committed in working capital was considered, that is, equal to the sum of the changes that occur in working capital throughout the entire economic life of the Project (Expansión, 2021).

RESULTS AND DISCUSSIONS

CELLULOSE QUANTIFICATION AND IDENTIFICATION

According to our research and documentary studies, King Grass in Colombia is a perennial plant that grows in various soil conditions and can be harvested multiple times a year. Additionally, it is a hybrid plant that does not compete with edible crops and has a high nutrient absorption capacity, allowing it to grow rapidly and reach significant heights, resulting in substantial biomass production (Botero-Londono, Celis-Celis, & Botero-Londono, 2021; Cardona, Rios, Peña, Peñuela, & Rios, 2016). In the literature, it is reported that Colombia annually produces 40 to 60 tons of this grass per hectare (Cardona et al., 2016). Furthermore, the nature and size of the plant greatly facilitate its transportation, and it is not toxic or difficult to handle.

The average overall yield for obtaining dry powdered biomass from harvested King Grass was 13.1%, with a standard deviation of less than 2%, and a coefficient of variation of less than 1%. The average yield for cellulose

extraction using the alkaline peroxide method was 47.8%, with standard deviations and coefficients of variation of 2.5 and 3.2, respectively. Although there are no reports in the literature regarding the yields of biomass acquisition and cellulose extraction from this grass, the results obtained are significantly high compared to those achieved with other types of biomasses(Rodríguez, Díaz, & Folgueras, 2012)todas ellas lineales, basadas en el contenido de los componentes estructurales expresado en % en peso, base seca y libre de extraíbles. Estas ecuaciones dependen de: un solo componente (lignina, holocelulosa o celulosa.

The results in **Table 4** depict the carbohydrate content of the raw biomass and the delignified biomass. The analysis of the chemical composition of raw biomass reveals percentages of 3.62%, 80.40%, 38.37%, and 42.03% for lignin, holocellulose, α-cellulose, and hemicellulose, respectively. The final cellulose content obtained after delignification by the alkaline peroxide method increased significantly, indicating that the proposed treatment successfully broke down most of the hemicellulose-lignin bonds, allowing for high cellulose percentages. Additionally, the lignin content decreased, indicating optimal delignification and resulting in zero values for this carbohydrate. Furthermore, the values obtained for hemicellulose suggest that the transition from cellulose 1 to cellulose 2, the thermodynamically more stable crystalline structure of cellulose, was not entirely successful.

FTIR-ATR spectra of the commercial and isolated cellulose (**Figure 5**) are very similar, both spectra show an absorption band at 3391cm^{-1} assigned to hydroxyl groups stretching. Bands at 2906 cm^{-1} and 1373 cm^{-1} are assigned to stretching and deformation vibrations of C-H group in glucose unit. The absorption band at 898 cm^{-1} is characteristic of β-glycosidic linkage between glucose units. Moreover, the signal at 1061cm^{-1} is assigned to -C-O- group of secondary alcohols and ethers functions existing in the cellulose chain (Abderrahim et al., 2015; Thakur, Sharma, Ahlawat, Bhattacharya, & Goswami, 2020) classed as biopolymer, was synthesized by condensation of succinic acid with a lower excess of (1, 4.

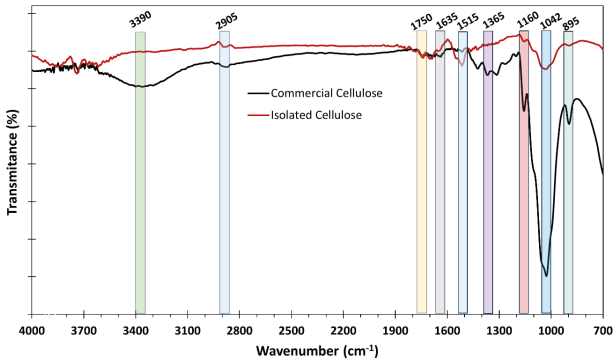

Figure 5. FTIR-ATR spectra of the commercial and isolated cellulose.

GRAPHENE SYNTHESIS AND IDENTIFICATION

Figure 6 reveals the spectra of both materials (commercial and synthesized graphene), which show a pronounced UV absorption band at 270 nm assigned to the sp2 hybridization of the C=C bonds of graphene. In addition, in **Figure 7**, the Raman spectroscopy results for both commercial and synthesized graphene materials are presented. In both materials, distinctive features in the Raman spectra include the G peak around 1580 cm^{-1} and the 2D peak around 2700 cm^{-1}. These peaks are attributed to the in-plane vibrations of sp2 carbon atoms and second-order zone boundary phonons, respectively. The presence of the D peak at 1336 cm^{-1} is indicative of first-order zone boundary phonons, suggesting the existence of defects or edge effects in the graphene (Gürünlü, Taşdelen-Yücedağ, & Bayramoğlu, 2020; Tyurnina et al., 2020; S. Wang, Wang, & Ji, 2017).

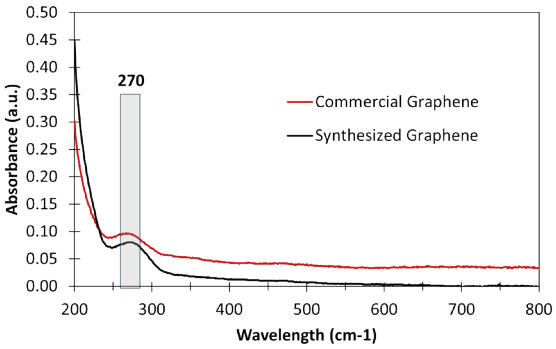

Figure 6. UV-vis absorption spectra of commercial and synthesized graphene.

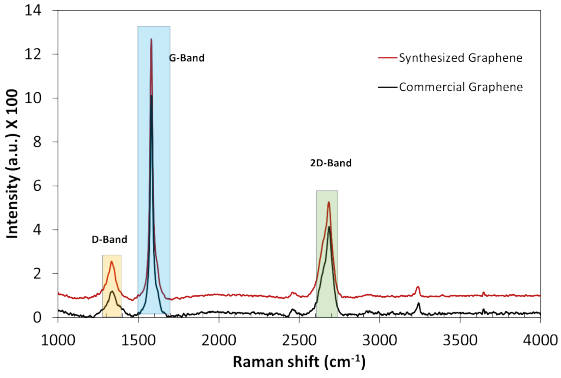

Figure 7. Raman spectra of commercial and synthesized graphene.

TECHNICAL-ECONOMIC ANALYSIS

Table 5 presents the prefeasibility results, including the initial investment values (over 600 million pesos), equipment depreciation (over 18 million), and a salvage value (over 180 million). Additionally, based on the assumptions made, the technical-economic analysis highlights three profitability parameters to infer whether the project is economically viable or not.

The Net Present Value (NPV), which remains highly positive throughout the entire project's life, indicates the recovery of the investment during the project's useful life, resulting in significant profits. The recovery of the investment is even observed within the first year. Regarding the Internal Rate of Return (IRR), it converges to a highly positive value, indicating the investment's breakeven point, suggesting that there is no need to extend the periods or consider other alternatives or scenarios. Additionally, the Benefit-Cost Ratio clearly demonstrates that the benefits outweigh the costs, with revenues sufficient to cover project expenses, generating economic gains (**Table 6**).

Ítem	Value
Initial investment*	$604.2
Depreciation*	$18.8
Salvage value*	$182.7
NPV*	$11,099
IRR	421.5 %
B/C ratio	37.74

Table 6. Results of the Economic prefeasibility study (in millions of COP*)

Moreover, this scientific research, in a general sense, highlights that with the reference patent, a graphene concentration of 99% is achieved. However, a significant gap in the patent is observed, which pertains to the lack of information regarding the yields obtained in the various stages comprising the graphene synthesis process. This information gap extends from the raw material pretreatment to the final phase of material synthesis. The omission of these performance data in the patent poses a challenge in the context of this research, as it hinders a proper comparison between the results obtained in this study and what is reported in the reference patent regarding biomass losses at each unit of operation. Therefore, it is crucial that the patent provides accurate and detailed data on yields at each stage of the process. This would enable a more precise evaluation of the feasibility and efficiency of graphene synthesis from King Grass, ultimately contributing to the advancement and successful implementation of such methodologies in future research and larger-scale production applications.

Period	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Sales*	2,285	2,365	2,447	2,533	2,622	2,713	2,808	2,907	3,008	3,113
Investments*	492	515	540	566	593	621	651	682	715	750

Table 5. Income and investments of the Project (in millions of COP*)

CONCLUSIONS

- The results regarding yields and chemical composition of King Grass biomass suggest that this abundant forest residue could be an economic and interesting opportunity in Colombia for use as a raw material for cellulose production via the alkaline peroxide method. However, the results of the technical-economic analysis indicate that the considered routes for graphene synthesis do not favor the associated costs.

- The results demonstrate that obtaining graphene from King Grass waste on a laboratory scale is technically and economically viable under current conditions, as revenues exceed expenses. Therefore, it is necessary to thoroughly analyze the possibility of implementing this production system on a pilot or industrial scale, as there is a business opportunity that would make future investment in graphene production attractive.

- Concerning social aspects, processing graphene from King Grass waste on an industrial scale can create employment opportunities in rural or agricultural areas, which can be beneficial for local communities. Furthermore, research and development of techniques to obtain graphene from renewable materials like King Grass can drive technological innovation and foster collaboration between industry and academia.

- It is possible to propose sustainable graphene production from King Grass waste. Additionally, it could provide access to cutting-edge technologies and advanced materials to communities that would otherwise not have access to them. Moreover, obtaining graphene from King Grass waste presents environmental benefits by reducing plant waste and promoting sustainable agricultural practices, as well as social benefits by generating employment and fostering technological innovation. However, it is essential to consider that further research and technological development will be required to fully evaluate these impacts and ensure the feasibility and sustainability of this practice.

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