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Changing Something Old to Something New: Turning Palo Santo Tree Residuals into a Sustainable Commodity

May 3, 2022

Abigail Cummings, Sofi Murray, Brandon Nieto, and Shannen Preble

NELIXIA

Changing Something Old to Something New:

Turning Palo Santo Tree Residuals into a Sustainable Commodity

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by

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Abstract

The wood of the palo santo tree of the South American Chaco is a dense hardwood with aromatic properties. The essential oil compounds within the tree are often extracted and sold to be used in perfumes, cosmetics, and for medicinal uses. This project addresses alternative uses for the sawdust byproduct for the company Nelixia, which is mainly responsible for the extraction of essential oils from palo santo. Through interviews, literature research, and technical experiments, the team gathered qualitative and quantitative data to offer suggestions for viable alternative uses for the factory. We determined that using the residuals for biofuel in the form of a compact briquette was the most viable option, though several other options were also determined to mitigate the residual accumulation.

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Executive Summary

Palo santo (*Gonopterodendron sarmientoi*) is one of the most recognizable woods in Paraguay. This highly desired tree can be found in scarce numbers in select parts of the Chaco region of South America. It is a highly dense wood that is used in various handicrafts and construction materials for homes and commercial buildings (Mereles and Perez de Molas, 2008)[1]. It is also desired for its distinguishable aromatic properties. The aromatic oils embedded into the bark of the wood are often extracted and sold to be used in the perfume and cosmetic industries (Carrión-Paladines, 2019)[2]. This is usually done through the process of steam distillation, which is the practice used by Nelixia, the sponsor of this project. The Nelixia factory in Paraguay is mainly responsible for the extraction of palo santo crude oil and exports the majority of their products to vendors in Europe. To get the oil, the factory grinds the wood into material that resembles sawdust, after which it is steam distilled under high pressure for twenty-four hours (Nelixia, 2021b)[3]. After the oil is collected, piles of residual palo santo "pulp" remain, taking up space on company property.

Problem Statement

The piles of palo santo residual has reached just under 500 tons and has become an increasing burden for the factory. It has also presented some potential hazards to the working environment at Nelixia. Given this project opportunity, *the team's overall project goal was to create viable options for an alternative use for the palo santo residual to help mitigate the accumulation on company property*. The options that the team presented to Nelixia were designed to be overall carbon neutral, and either help Nelixia save money or help to create a net profit for the factory.

Objectives and Methods

In order to meet the overall project goal, the team implemented three objectives:

1.) investigate the physical properties of palo santo residuals;
2.) understand and communicate safety concerns regarding the residuals; and
3.) determine the viability for Nelixia to employ alternative uses of palo santo residuals.

To meet the first objective, the team conducted literature research using scientific databases, such as Google Scholar and ScienceDirect to gain baseline knowledge about the characteristics of palo santo. The team also designed several technical experiments to measure properties such as heat capacity and calorific content.

To meet the second objective, the team conducted a series of key informant interviews. It was through these interviews that the team first learned of potential hazards in regards to the

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[1] Mereles, F., & Pérez de Molas, L. (2008). *Bulnesia sarmientoi Lorentz ex Griseb., (Zygophyllaceae): estudio de base para su inclusión en el Apéndice II de la Convención CITES,* http://awsassets.panda.org/downloads/publicacion_sobre_palo_santo.pdf.

[2] Vinicio Carrión-Paladines et. al., (2019). Biodegradation of residues from the palo santo (Bursera graveolens) essential oil extraction and their potential for enzyme production using native xylaria fungi from southern Ecuador. https://doi.org/10.3390/fermentation5030076.

[3] Nelixia. (2021d). Gaiacwood. https://www.nelixia.com/gaiacwood/.

management of the residuals, specifically involving the factory boiler. The interviewee communicated with the team of the large influx in temperature and size of the flames of the boiler when residuals are added, creating a potentially dangerous circumstance as well as a loss of efficiency.

The final objective was met with a cost analysis. This analysis compares all of the findings and possible avenues that the factory could take to mitigate their residuals and helps the factory determine which option is the most economically feasible.

Findings

Through analyzing both quantitative and qualitative data, the team collected the following findings regarding the possible avenues the Nelixia factory take to implement and alternative use to the palo santo residuals:

- **Using Palo Santo Residuals as a Source of Biofuel in the Form of Briquettes:** This is the most viable alternative use for the Nelixia factory because their source of fuel is already at the factory; therefore, it is inexpensive. In the form of a compressed briquette, formed with a type of binder such as flour, the company can consume large amounts of residuals by buying a briquette press for ₲89 million. The briquettes also eliminate the large increase in size and temperature of the flames of the boiler at the factory, thus eliminating a potential safety concern.
- **Selling the Residuals to an Outside Company:** the team was able to contact two potential clients and through a series of key informant interviews, determined that they are willing to buy the residual outright from Nelixia, with certain humidity conditions, to use in their own industrial practices. This would immediately solve the problem of residual buildup on company property and could also serve as a potential avenue to foster a long-term business relationship for Nelixia.
- **There were No Significant Differences in the Data of Certain Technical Experiments:** Two of the technical experiments conducted by the team resulted in data with insignificant differences, our plant experiment and our compost experiment. This is due to the fact that the team only had a limited amount of time to carry out these procedures, and therefore recommends a continuation of these analyses to measure the residuals's potential as a component in mulch or compost.

Recommendations

Based on the results of the team's qualitative and quantitative data analysis, the team recommends the following:

- **Conduct a Test Using Briquettes in the Nelixia Factory Boiler:** The team was only able to create prototype briquettes of a much smaller scale compared to the industrial scale on which Nelixia would be operating. While the prototypes burned well in the boiler at Nelixia, it is important for Nelixia to conduct tests using their own, larger size briquettes to get a better understanding of how they function as a form of biofuel.
- **Implement a Feasibility Study in Regards to Drying Residuals to Sell to Outside Clients:** Both of the potential clients that the team was able to contact expressed interest in the final residual product having a very low water content. Therefore, the team is recommending implementing a feasibility study regarding different drying techniques. These techniques include an industrial drying system, covering the residuals using a shed, and sun drying.

- **Conduct More Tests Using Palo Santo Residuals as a Form of Mulch and Compost:** Since there was not enough data to accurately conclude a concrete result due to time constraints, the team is recommending a continuation of these experiments. This way, Nelixia can continue to explore more alternative options and potentially create more business relationships with outside companies. The team also recommends using the residuals on different types of plants, as the plants used in the original experiments take a long time to reach maturity.

Conclusion

This project found different alternative uses for palo santo residuals in order to help the Nelixia factory mitigate their accumulation while simultaneously eliminating potential hazards and saving the company money. Based on the results of the methodologies implemented, the team hopes that Nelixia has the necessary information to reduce their residuals in a manner that brings in a carbon neutral net profit to the factory, and can be sustained over a long period of time.

Cambiando Algo Viejo por Algo Nuevo: Convirtiendo Residuales del Árbol de Palo Santo en un Producto Sostenible

by Abigail Cummings, Sofi Murray, Brandon Nieto, and Shannen Preble

Informe Executivo

Palo santo (*Gonopterodendron sarmientoi*) una de las maderas más reconocidas en Paraguay. Este árbol deseado se puede encontrar en escasos números y lugares dentro de la región del Chaco de Sudamérica. Es una madera altamente denso que se utiliza en diversas artesanías y materiales para construcción para hogares y edificios comerciales (Mereles y Perez de Molas, 2008)[1]. También es deseado por las propiedades aromáticas que son distinguibles. Los aceites aromáticos incrustados en la corteza de la madera a menudo son extraídos y vendidos para utilización en industrias de perfume y cosméticas (Carrión-Paladines, 2019)[2]. Típicamente la esencia es extraída por el proceso de destilación al vapor, que es la práctica que realiza Nelixia, el patrocinador de este proyecto. Nelixia (en Paraguay) es principalmente responsable de la extracción de esencia cruda de palo santo y exporta la mayoría de sus productos a proveedores en Europa. Para extraer el aceite, la fábrica muele la madera en un aserrín, después de lo cual se destila al vapor a alta presión durante veinticuatro horas (Nelixia, 2021b)[3]. Después de que se recolecta el aceite, quedan montones de "pulpa" residual de palo santo, ocupando espacio en la propiedad de la compañía.

Declaración del Problema

Las pilas de residuos de palo santo han alcanzado casi 500 toneladas y se han convertido en una carga creciente para la fábrica. También ha presentado algunos peligros potenciales para el entorno de trabajo de Nelixia. Dada esta oportunidad de proyecto, el objetivo general del proyecto del equipo fue crear opciones viables para un uso alternativo del residuo de palo santo para ayudar a mitigar la acumulación en la propiedad de la empresa. Las opciones que el equipo presentó a Nelixia fueron diseñadas para ser carbono neutral en general, y ayudar a Nelixia a ahorrar dinero con el tiempo o ayudar a crear un beneficio neto para la fábrica.

Objetivos y Métodos

Para cumplir con el objetivo general del proyecto, el equipo implementó tres objetivos:

1.) Investigar las propiedades físicas de los residuos de palo santo;
2.) Comprender y comunicar las preocupaciones de seguridad con respecto a los residuos; y
3.) Determinar la viabilidad para que Nelixia emplee usos alternativos de los residuos de palo santo.

Para alcanzar el primer objetivo, el equipo realizó investigaciones literarias utilizando bases de datos científicas como Google Scholar y ScienceDirect para obtener conocimientos

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[1] Mereles, F., & Pérez de Molas, L. (2008). *Bulnesia sarmientoi Lorentz ex Griseb., (Zygophyllaceae): estudio de base para su inclusión en el Apéndice II de la Convención CITES,* http://awsassets.panda.org/downloads/publicacion_sobre_palo_santo.pdf.

[2] Vinicio Carrión-Paladines et. al., (2019). Biodegradation of residues from the palo santo (Bursera graveolens) essential oil extraction and their potential for enzyme production using native xylaria fungi from southern Ecuador. https://doi.org/10.3390/fermentation5030076.

[3] Nelixia. (2021d). Gaiacwood. https://www.nelixia.com/gaiacwood/.

básicos sobre las características del palo santo. El equipo también diseñó varios experimentos técnicos para medir propiedades tales como capacidad calorífica y contenido calorífico.

Para alcanzar el segundo objetivo, el equipo realizó una serie de entrevistas con informantes clave. Fue a través de estas entrevistas que el equipo se enteró por primera vez de los peligros potenciales en lo que respecta a la gestión de los residuos, específicamente en relación con la caldera de la fábrica. El entrevistado se comunicó con el equipo de la gran afluencia de temperatura y tamaño de las llamas de la caldera cuando se añaden residuos, creando una circunstancia potencialmente peligrosa.

El objetivo final se cumplió con un análisis de costos. Este análisis compara todos los hallazgos y posibles vías que la fábrica podría tomar para mitigar sus residuos y ayuda a la fábrica a determinar cuál opción es la más factible económicamente.

Los Descubrimientos

A través del análisis de datos cuantitativos y cualitativos, el equipo recopiló los siguientes hallazgos sobre las posibles vías que la fábrica de Nelixia puede tomar para implementar y utilizar de manera alternativa los residuos del palo santo:

- **Uso de Residuos de Palo Santo como Fuente de Biocombustible en Forma de Briquetas**: Este es el uso alternativo más viable para la fábrica de Nelixia. Esto se debe a que su fuente de combustible ya está en la fábrica, por lo tanto es increíblemente barato. En la forma de una briqueta comprimida, formada con un tipo de aglutinante, esto permite a la empresa pasar grandes cantidades de residuos a un precio relativamente bajo. Las briquetas también eliminan el gran aumento de tamaño y temperatura de las llamas de la caldera en la fábrica, eliminando así un posible problema de seguridad.
- **Venta de los Residuos a una Empresa Externa**: A través de una serie de entrevistas con informantes clave, el equipo fue capaz de contactar a dos clientes potenciales que están dispuestos a comprar el residuo directamente a Nelixia, con ciertas condiciones de humedad, para su uso en sus propias prácticas industriales. Esto resolvería inmediatamente el problema de la acumulación residual en la propiedad de la compañía y también podría servir como una vía potencial para fomentar una relación comercial a largo plazo para Nelixia.
- **No Hubo Diferencias Significativas en los Datos de Ciertos Experimentos Técnicos**: Dos de los experimentos técnicos realizados por el equipo resultaron en datos con diferencias insignificantes, nuestro experimento de planta y nuestro experimento de compost. Esto se debe al hecho de que el equipo sólo tuvo una cantidad limitada de tiempo para llevar a cabo estos procedimientos, y por lo tanto recomienda una continuación de este análisis para medir el potencial de los residuos como un componente de mulch o abono orgánico.

Recomendaciones

Sobre la base de los resultados del análisis de datos cualitativos y cuantitativos del equipo, el equipo recomienda lo siguiente:

- **Realice una Prueba Utilizando Briquetas en la Caldera de la Fábrica de Nelixia**: El equipo sólo pudo crear briquetas prototipo de una escala mucho menor en comparación con la escala industrial en la que Nelixia estaría operando. Mientras que los prototipos se quemaron bien en la caldera de Nelixia, es importante que Nelixia realice pruebas utilizando sus propias briquetas de mayor tamaño para obtener una mejor comprensión de cómo funcionan como una forma de biocombustible

- **Implementar un Estudio de Factibilidad con respecto a la Secado de Residuales para Vender a Clientes Externos**: Ambos clientes potenciales con los que el equipo fue capaz de contactar expresaron interés en el producto residual final con un contenido de agua muy bajo. Por lo tanto, el equipo recomienda la implementación de un estudio de factibilidad sobre diferentes técnicas de secado. Estas técnicas incluyen un sistema de secado industrial, cubriendo los residuos usando un cobertizo, y secando al sol.
- **Realizar más Pruebas Usando Residuos de Palo Santo como una forma de Mulch y Abono Orgánico**: Dado que no había suficientes datos para concluir con precisión un resultado concreto debido a limitaciones de tiempo, el equipo está recomendando una continuación de estos experimentos. De esta manera, Nelixia puede continuar explorando más opciones alternativas y potencialmente crear más relaciones comerciales con empresas externas. El equipo también recomienda utilizar los residuos en diferentes tipos de plantas, ya que las plantas utilizadas en los experimentos originales tardan mucho tiempo en alcanzar la madurez.

Conclusión

Este proyecto encontró diferentes usos alternativos para los residuos de palo santo con el fin de ayudar a la fábrica de Nelixia a mitigar su acumulación, al tiempo que elimina los posibles peligros y ahorra dinero a la empresa. Sobre la base de los resultados de las metodologías implementadas, el equipo espera que Nelixia tenga la información necesaria para mitigar sus residuos de una manera que traiga a la fábrica un beneficio neto neutro en carbono, y que pueda mantenerse durante un largo período de tiempo.

Acknowledgements

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G	BN	SM
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Chapter 1: Introduction & Background

The Nelixia factory in Paraguay, the sponsor of this project, extracts oils from palo santo (*Gonopterodendron sarmientoi*) wood for export. To get the oil, the factory grinds the wood into material that resembles sawdust, after which it is steam distilled under high pressure for twenty-four hours (Nelixia, 2021b). The extracted oil is then sold for pain relief for conditions, such as arthritis, headaches, and throat pain (Nunez, 2020) as well as in the perfume and cosmetic industries (Carrión-Paladines et al., 2019). After the oil is collected, piles of residual palo santo "pulp" remain, taking up space on company property. The pulp has become an increasing burden and potential danger for the factory as the amount of residuals has reached almost five hundred tons (anonymous interviewee, personal communication, April 25, 2022).

This chapter introduces background about palo santo's history, current uses, and conservation status. It then describes the type of work being done at the Nelixia factory in Paraguay as well as potential alternative uses for palo santo wood residuals. While the team was able to identify uses of both palo santo wood and essential oil, we discovered a gap in investigations regarding specifically the residual pulp. This gave the team the opportunity to further investigate not only how to mitigate the residual accumulation, but also how to turn something burdensome to something profitable that is also considered to be carbon neutral or 'sustainable.'

Given this opportunity, the team's goal was to propose several options for the Nelixia factory to mitigate their residual buildup; these options could bring in a carbon neutral net profit to Nelixia while creating a safer working environment. The team attempted to achieve this goal by completing three objectives:

1.) investigate the palo santo residuals and the effect that it has on the Nelixia factory;
2.) understand and communicate safety concerns regarding the residuals; and
3.) determine the viability for Nelixia to employ alternative uses of palo santo residuals.

1.1: Background on Palo Santo

One of only two landlocked countries in South America (along with Bolivia), Paraguay is home to about seven million people (World Population Review, n.d.), one-third of South America's Gran Chaco (Miller et al., 2015), and the endangered palo santo (*G. sarmientoi)* tree. This unique tree can be found in the Gran Chaco region of South America.

The common name "palo santo" means "holy tree" in Spanish. The name alone is indicative of how the tree has historically been viewed by local inhabitants and its unique place in the culture of people throughout the Gran Chaco region. Palo santo has been employed as a valuable medicinal tree with a variety of healing properties (Waller et al., 2012). Infusions of palo santo bark and leaves have been used as a blood cleanser, a diuretic to treat gastric pain, and a remedy for diseases such as syphilis, leprosy, gout, and rheumatoid arthritis (Waller et al., 2012).

Figure 1.1

Map of Gonopterodendron sarmientoi *in the Gran Chaco Region*

Note. From "BGCI 2018. Gonopterodendron sarmientoi. The IUCN Red List of Threatened Species. Version 2021-3" (2018) by Environmental Systems Research Institute, Inc. (Esri), is licensed under CC BY 4.0.

The palo santo tree has also been used by various industries for decades, primarily the timber trade and wellness industries. Argentina is currently the biggest supplier of palo santo timber, while Paraguay is the largest supplier of the essential oil (Waller et al., 2012). These industrial practices put indigenous communities of the Chaco, such as the Criollos (a group of people native to the northwestern Chaco), in a position where a piece of their culture – palo santo – is nearly extinct. Palo santo has been an integral part of their culture for hundreds of years, originating from both Spanish Christian practices and Quechua ancestral ceremonies (Scarpa, 2004). As such, the practices making palo santo endangered (IUCN, 2018) are also negatively affecting these communities that have a long cultural history with the tree.

Figure 1.2

*Palo Santo (*Gonopterodendron sarmientoi*) Tree Grown in Paraguay*

Note. From "Photo 66289652" (2015b, November) by Pablo Preliasco is licensed under CC BY-NC 4.0 https://www.inaturalist.org/photos/66289652.

1.2: Steam Distillation and Palo Santo Residual Basics

In order to gain a deeper comprehension of how palo santo residuals are produced, it is important to understand the details of the essential oil extraction process (guaiacol production), which generates the residuals as a byproduct. A common oil extraction method is steam distillation, which technically extracts the “fragrant alcohols” or water soluble compounds composing essential oils such as guaiacol (Schmidt, 2009, p. 88). The sections of the plants are utilized based on where the oil cells are located within the plant. In the case of palo santo, which is classified as a wood oil, the wood is used in the extraction, and sections of the tree are ground into slivers for easier access to the oil cells contained within the wood (Schmidt, 2009, p. 91). Nelixia accomplishes this by grinding the wood into chips, which are then steam distilled under pressure for twenty-four hours (Nelixia, 2021b).

During the steam distillation process, steam flows through the wood to extract the oil. The volatile oil compounds are carried away by the steam, which exits the heating chamber and flows through a condenser to cool the steam back to water. This is left to sit in a flask, allowing separation of the distillation water and the oil (Schmidt, 2009, pp. 100-102). The solid biomass materials remaining after the distillation process are the residuals that the team worked with.

The residuals obtained immediately following the steam distillation process could be damp as a result of steam flowing through it for a day. With much of the oil extracted, the residuals could also smell less aromatic than before. Both the dampness and fragrance of the residuals were therefore examined, comparing the residuals with unaltered palo santo wood and with wood chips prior to steam distillation.

Figure 1.3

Palo Santo Residuals at Nelixia Factory Grounds

Note. The image depicts the palo santo residuals on the Nelixia factory grounds. In the foreground of the picture, the residuals have begun the process of oxidation, changing to a dark green color, while to the left and back the residuals appear to be a traditional wood color. This image was provided by the team and taken with permission of the factory owner. Photo taken by Abigail Cummings.

1.3: Safety

The residuals created by the guaiacol production process have built up to a little under 500 tons in the past two years. In addition to occupying space on Nelixia's grounds, the residuals also present safety concerns. One safety issue is the possible buildup of methane within the pile of residuals as they are decomposing. This was first brought up during an interview with an expert in bioenergy. The interviewee expressed their concern for safety because of the methane being created in the anaerobic environment at the center of the pile (anonymous bioenergy expert, personal communication, April 7, 2022), leading the team to look more in-depth into the amount of methane that could be produced by these piles.

Another observed issue is that the addition of loose residuals to the boiler creates a large fluctuation of heat and pressure that could be potentially dangerous to the plant and anyone working within it. This was brought to the team's attention through an interview with an anonymous Nelixia worker. The team was also given a demonstration of the impact of adding loose palo santo residuals to the boiler, observing the large heat and pressure fluctuation first-hand.

1.4: Stakeholders

Nelixia was the most influential key stakeholder. Nelixia was the sponsor of the project and worked alongside the group. As a company, Nelixia benefits from freeing up space occupied by the palo santo residuals post oil extraction. They also benefit from a safer working environment and gaining a net profit through selling their residual byproduct (anonymous Nelixiaemployee, personal communication, March 30, 2022). Furthermore, the company's wishes significantly impacted the team, as ignoring the company's desires would contradict the goal of the project. The company could also elect to not accept the proposed profit opportunity if they feel their needs are being overlooked. Therefore, input from Nelixia was paramount in ensuring the success of the project.

Fundación Paraguaya was another key stakeholder, along with the Escuela Agrícola Cerrito, which they operate. The school rents property to the Nelixia factory (Fundación Paraguaya, n.d.). This therefore gives the foundation influence on the project. The school, on the other hand, could serve as a potential client, having some influence since a profit is desirable.

The third key stakeholder to this project was the palo santo tree itself. Palo santo's endangered conservation status on the IUCN Red List is paramount to this project (IUCN, 2018). Because the tree is necessary for the extraction of oil, and the project therefore cannot exist without the tree, the palo santo tree is a central stakeholder of this project. As such, factors such as how the tree will be impacted must be considered for every potential use studied.

1.5: An In-depth Review of Nelixia

Nelixia operates in Central and South America and uses many different sources for their products such as the palo santo tree, cardamom, patchouli, Peru balsam, and styrax. These are sourced and then refined into their final products in multiple countries, including Guatemala, Honduras, El Salvador, Peru, and Paraguay (Nelixia, 2021a).

With such a large-scale international company involved in harvesting wood and other natural resources, sustainability should always be a concern. In order to practice sustainable harvests and offset their carbon footprint, Nelixia has implemented a sustainability strategy to protect palo santo trees. An average of six trees per hectare are cut down at a time, ensuring that regeneration can occur. The forest is actively monitored through Nelixia's management plan, making sure that regeneration will continue and that the forest can prosper (Nelixia, 2021b). These steps are necessary to ensure that the harvested trees and plants are not put at further risk of extinction.

Figure 1.4

Map of Nelixia's Sourcing Operations

Note. This image depicts where Nelixia sources their materials for their products (Nelixia, 2021a).

1.6: Learning from Existing Wood Applications

Though there is a general lack specifically for uses of *G. sarmientoi* wood residuals, studies on applications of other wood byproducts were used as potential models. These included wood byproducts used for industrial and cleaning applications, biofuels, and insulation. To determine the wood byproduct's capabilities for industrial and cleaning applications, the enzymatic activity (specifically in regard to laccase, xylanase, and cellulase, enzymes with a strong presence in industrial and cleaning applications) was measured in the fungi on dead wood residuals. If the enzymatic activity matched or exceeded those in a control fungus, it would imply that the fungi had high enough enzymatic ability, meaning the residual wood could be used in the aforementioned industries (Carrión-Paladines et al., 2019).

With the second application (biofuel), various factors were used to calculate an estimated energy yield for various wood sources. This determined if there were any significant correlations between wood properties and energy yield, finding the main factors to be the amount of bark and the increment of dry matter (Oliveira et al., 2021). The energy yield could then be used in seeing if various woods could make a viable source of biofuel. The insulation application involved mixing wood residuals, along with other biomass waste, into cement panels to increase the insulative properties. This considered both the thermal and mechanical properties of the various panels, seeing how the additives impacted the properties. It was ultimately determined that the addition of wood impacted modulus of elasticity and thermal conductivity of the panels (Amiandamhen et al., 2021).

1.7: Summary

Developing an extensive background about palo santo's history, current uses, and potential applications that have yet to be explored was pivotal to understanding the team's project opportunity. Understanding more about Nelixia's operations also helped the team acknowledge the company's perspective regarding their residual accumulation. The team had noticed a gap in research regarding specifically palo santo wood residuals post-steam distillation, so investigating alternative palo santo wood applications established a fundamental baseline for developing our methodology to help mitigate the large amount of residuals on the factory grounds.

Chapter 2: Methodology

The goal of the project was to propose several options for Nelixia to mitigate their palo santo residual buildup. These options could potentially bring in a carbon neutral net profit to the factory while simultaneously creating a safer working environment. This goal was completed by following a set of three objectives:

1.) investigate the palo santo residuals and the effect that it has on the Nelixia factory;
2.) understand and communicate safety concerns regarding the residuals; and
3.) determine the viability for Nelixia to employ alternative uses of palo santo residuals.

2.1: Investigating the Palo Santo Residuals and their Effect on the Nelixia Factory

To get a full understanding of the residuals and how they affect the Nelixia workers, the team investigated the physical properties of the wood in addition to gaining a better understanding of how the operation is impacted by the residuals. These helped the team lay a foundation of understanding of our presented project opportunity. Social scientific and analytical practices were implemented throughout this process including literature research, experimental design, key informant interviews, and visual observations.

Literature Research and Chemical Composition

The team began with thorough literature research into the chemical composition of palo santo wood, finding scholarly articles in databases such as Google Scholar and ScienceDirect. This data was used to find a theoretical composition by subtracting a percentage of the oil compounds (provided by Nelixia) from the findings on the wood composition. Because there was a gap in research done specifically with palo santo wood residuals, a chromatography analysis on the wood residual would be needed for a more accurate composition. This would be useful for Nelixia to determine the viability of options outside of what the team considered. Through the help of our advisor, Professor Dorothy Burt, we attempted to organize a chromatography test on a sample of wood residual taken from the Nelixia, but we were unsuccessful in finding a laboratory within a reasonable distance of the factory that could have the analysis done in under seven weeks. This presented an opportunity that could be further explored at a later time.

Coffee Cup Calorimetry

After researching the chemical composition, the team began to design technical experiments. The team started with a coffee cup calorimetry experiment. This was a simple experiment to help determine the overall heat capacity and heat transfer of the palo santo residuals. This experiment was conducted in order to get more information about the residuals' potential as a fuel source, and to determine how heat was transferred into its surroundings. A coffee cup calorimeter consists of a styrofoam cup, a thermometer, water, and a reactant placed inside of the cup, in this case, the residuals. The water was then heated, and temperature measurements were taken before and after adding heat. This experiment was based around the principle that there was no heat loss to the surrounding air because the heat energy lost or gained by the system was equal to the energy lost or gained to the surroundings (Chow, 2020).

Key Informant Interviews & Visual Observations

To gain further knowledge regarding how the physical characteristics of palo santo wood residuals impact the Nelixia factory, we conducted seven semi-structured key informant interviews (detailed in Table 2.1). Using semi-structured interviews allowed the direction of the interview to change based on the answers provided (Mod U, 2016a).

Table 2.1

Interview Information

Date	Interviewee	Interviewer	# People Present	Length	Location
Investigating the Palo Santo Residuals and Their Effect on the Nelixia Factory					
3/28/22	Nelixia Worker 1	Abby	6	8 mins, 54 secs	Nelixia factory
3/28/22	Nelixia Worker 2	Abby	6	7 mins, 52 secs	Nelixia factory
3/28/22	Nelixia Worker 3	Abby	6	7 mins, 40 secs	Nelixia factory
3/28/22	Nelixia Worker 4	Abby	6	7 mins, 43 secs	Nelixia factory
3/28/22	Nelixia Worker 6	Abby	5	8 mins, 5 secs	Nelixia factory
3/29/22	Nelixia Engineer	Sofi	6	17 mins, 25 secs	Ag. school
3/30/22	Nelixia Counterpart	Abby	5	9 mins, 24 secs	Nelixia factory
Understand and Communicate Safety Concerns Regarding the Residuals					
4/6/22	Nelixia Worker 7	Sofi	4	15 mins, 34 secs	Nelixia factory
4/7/22	Biofuel Expert	Brandon	3	37 mins, 12 secs	Ag. school
Determining the Viability for Nelixia to Implement Alternative Uses					
3/28/22	Ag. School Representative	Sofi	3	13 mins, 21 secs	Ag. school

Date	**Interviewee**	**Interviewer**	**# People Present**	**Length**	**Location**
4/6/22	Dairy Plant Representative	Abby	4	14 mins, 26 secs	Ag. school
4/12/22	Mazarrón Representative	Abby	8	44 mins, 42 secs	Mazarrón factory
4/12/22	Iris Representative	Sofi	6	38 mins, 37 secs	Zoom
4/25/22	Iris Representative	Abby	7	18 mins, 45 secs	Iris factory

Note. The length of the interview includes the reading of the consent script for interviews in which the interviewer read the script aloud. "Ag. school" is an abbreviated and translated title for the Escuela Agrícola.

A key informant interview is an interview with a stakeholder that holds previous expertise or knowledge about the subject of the interview (The University of Illinois, n.d.). Our counterpart was the key informant in this process. After this interview, the snowball method was used to identify more interviewees. (Berg & Lune, 2011, p. 53). This way, our counterpart was able to suggest other qualified candidates for the questions (Berg & Lune, 2011).

All interviewees were given a consent script (Appendix A) prior to the interview. This script was either read aloud to the interviewee by the interviewer or was presented to the interviewee to read. All interviewees were then asked to verbally state if they agreed to the consent script. This agreement was audibly recorded.

These interviews were then transcribed and analyzed. The transcriptions were, for the most part, done manually by the team by repeatedly listening to the audio recordings (taken using the voice memo application on the iPhone after getting explicit verbal consent to record) and writing down, to the best of our ability, what both the interviewer and interviewee were saying. For some of the longer interviews, the transcription services Maestro and AmberScript were used to aid in the process, though the team still carefully listened to the recording several times and adjusted the transcriptions as needed.

The process of analyzing them was done through coding. The coding was done in Google Docs by breaking down the transcripts taken during the interview to determine themes and patterns within them (Mod U, 2016b). Each theme was assigned a color (which was indicated at the top of each document with a legend). The team then carefully read through the transcript and highlighted any occurrence of that theme in the designated color (Saldaña, 2011). Some interviews were also translated into English before coding to make it easier for the team to recognize themes. Translations were primarily done manually by the team, though SpanishDict was occasionally consulted. These interviews were also the main method used in understanding how the workers were affected by the residuals. Some of our most important key informants were a group of factory workers at Nelixia.

The team also investigated the factory boiler. This was done through visual observation as well as photography and note taking. The team members noted specifically how the residuals were added to the boiler, as well as details such as the percentage of residuals used and the operating conditions (temperature and pressure) of the boiler.

2.2: Understand and Communicate Safety Concerns Regarding the Residuals

Determining safety concerns was an important part of the process in determining in what ways the residuals could be used as well as what dangers they currently present to the Nelixia factory. The team used several methods to determine this including visual observations, key informant interviews, and literature reviews.

Visual Observations

The first thing the team did when they arrived at the Nelixia factory was take a tour of the plant. We specifically paid close attention to the fueling process, and asked questions regarding how the steam was created to extract the oil. Since the team was not able to take photos or videos[1], we relied on visual observations to extract initial information.

Key Informant Interviews

In order to obtain more in-depth information on the safety concerns found in the team's visual observations, the team conducted two key informant interviews (Table 2.1). These interviews led to the discovery that the piles of residual were likely creating pockets of methane within them. To research this further, the team did literature research on the theoretical methane production of the pile.

Literature Research

Scientific literature provided the team information about past research conducted with residuals, problems that they can cause, as well as more information on how to solve the problems the team noticed previously. The team utilized scientific databases like Google Scholar and ScienceDirect to obtain the majority of the research information. Using these databases, the team found two articles that communicated the possible problems that are occurring, one involving the production of methane within wood chip piles and the other talking about how the geometric shape of biofuel plays a major part on the speed at which it burns.

2.3: Determining the Viability for Nelixia to Implement Alternative Uses

Determining the viability of options realized throughout the earlier stages of the project was paramount to producing recommendations for Nelixia. The previously collected data was used to guide the techniques employed to achieve this final objective, though some additional methodology was needed to get a stronger sense of what would truly work for Nelixia. These methods included another round of interviews, contacting potential clients, and testing the functionality of the residuals for some options.

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[1] During the tour, the team took notes, but no photos or videos were taken due to secret proprietary processes.

Key Informant Interviews

To gain insight on the various options, the team conducted five interviews, making a total of fifteen interviews throughout the entire process (Table 2.1), that were developed through snowball sampling (described in 2.1). To find a deeper understanding of the different choices, semi-structured interviews were used. The interviews served to gauge the plausibility of varying options composed of experts in fields such as biofuel as well as potential clients.

Factory Tours

The team also used factory tours to understand the viability of various options. Tours were conducted at the Nelixia factory, Ceramica Mazarrón (a ceramics factory close to the Nelixia factory), and Iris (a mosquito repellent company). The team made visual observations at these factories of the methods employed at each location. Pictures and videos were also taken at the Mazarrón factory, though the other two factories prohibited the use of cameras.

Scientific Experimentations

Using the information surrounding which options seemed the most promising, the group developed several additional scientific experiments to gain a rudimentary idea of the actual behavior of the residuals. As many of these experiments would take a minimum of several months to get any real insight and require some equipment that was not available, they should be continued and/or repeated by Nelixia to get more realistic and useful data. The three options that the team examined were briquettes, fertilizer/mulch, and compost.

For the first option, the team made briquettes through mixing residuals with binders and letting the resulting briquettes dry (described in depth in Appendix B). The briquettes were then set on fire (method described in Appendix C), and visual observations, such as if the briquettes burned at all and how sustainable the fire was, were made. For the second option, the changes in height and leaf size of sixteen plants in varying amounts of residual were measured (method described in depth in Appendix D), giving a basic look into how residuals as a fertilizer or mulch affected plant growth. With the final option, various mixtures of residuals and composting agents were created, and the mixtures were visually observed to see if there was any noticeable difference in the decomposition of one mixture over the other (method described in more depth in Appendix E).

Cost Analysis

A cost analysis is necessary to accurately assess what the best possible method a company can use when faced with a challenge. To complete this analysis, several steps were used. The process as outlined by Indeed consists of a total of eight steps, though due to the limited information available, and the fact that a very basic cost analysis was being conducted, the team only went through three of these steps. The first step was to determine the requirements for each method of using the residual. The next step was to research the cost of required materials. The final step of the cost analysis was to compare the different methods to find which would be the most cost effective (Indeed Editorial Team, 2021).

The required materials needed for the first step consisted of materials, transportation, and labor, which are common factors that play into process costs (Bragg, 2021). To determine the necessary materials, the team used findings from literature research, interviews, and factory tours, and these machines and general materials were sorted into a table (Appendix F). Transportation was only included for uses in which the final product would be used outside of Nelixia, and labor was included for all uses since at least some additional labor would be needed.

For the second step, various retailers such as IndiaMART and Amazon were used to find costs for the materials. Accurate transportation costs could not be obtained, so the transportation distance was used to break the costs into a low, medium, or high expense. The labor costs were handled in a similar manner (broken into high or low cost) as an accurate estimate on labor costs was not established (Indeed Editorial Team, 2021).

The comparison of different options was the final step in the cost analysis. This was done by comparing all of the one-time payment items (e.g., machinery) and then comparing things that would be overhead expenses (e.g., transportation and labor) (Indeed Editorial Team, 2021). This was used to figure out if the investments were better in the short term or long term as well as to get a basic understanding of which options had higher overall expenses. A more thorough cost analysis would be required in the future to truly see whether each option would be worthwhile, though more information, especially the estimated income for each option, would be needed for such an analysis (Indeed Editorial Team, 2021).

Chapter 3: Findings, Analysis, & Recommendations

The following chapter explains the findings from the team's social science and technical research. The findings are listed in chronological order. Key data tables and figures explaining important data points can be found in this chapter, and all calculations can be found in the appendices.

3.1: Literature Research

The purpose of conducting literature research was to establish preliminary knowledge in terms of formulating alternative uses for the palo santo residuals. Scientific databases such as Google Scholar and ScienceDirect provide peer reviewed articles that helped to solidify the team's understanding of the project opportunity. Of all the topics that the team explored, there were three areas of research – microorganisms, chemical composition, and machinery – that we determined to be the most valuable for meeting the group's goal and objectives.

Microorganisms

The idea of utilizing microorganisms to break down the palo santo residuals, specifically with the goal to use the broken down residuals for composting, came up early in the team's research, specifically when investigating the physical properties of palo santo. In 2004, Argentinian scientists in the northern part of the Chaco conducted a study with a main goal of discovering a natural component that would ultimately be used in antibiotics. The team investigated oil extracts from thirty-nine different species of plants native to this part of the Chaco, including the extract of palo santo (*G. sarmientoi).* The data concluded that palo santo, along with other plant species within the group of thirty-nine, were not resistant to microbial growth (Salvat et. al, 2004). While it was recommended that more studies were needed, this gave the team preliminary ideas about possible alternative uses such as a component of mulch or compost.

Chemical Composition

Determining the chemical composition was a strongly suggested early step in finding alternative uses for palo santo residuals as the composition would highlight uses that would be hindered by the presence of or lack of specific compounds. It also would offer new avenues to explore based on current uses surrounding those compounds. Although a majority of the articles found about palo santo's composition were solely focused on the composition of the oil, through extensive research, the group eventually found two articles that had some information about the composition of other parts of the plant.

The first article was about a study done at a university in Argentina in which chromatography was performed on the wood, leaves, flowers, fruits, and seeds of many trees in the zygophyllaceae family, including *G. sarmientoi*. Thus, some information was found for the chemical makeup of the palo santo wood, specifically the phenols present. A strong flavonoid presence was found in all aspects of the plant, including the wood, with eight main flavonoids detected (Poggio, 1977).

The second article was a dissertation from a Portuguese university that did a chemical study of palo santo. This gave a breakdown of all the compounds found in the various palo santo extracts, not just the guaiacol extracted by Nelixia. The study found a total of fifty-four compounds, which were primarily phenols and alcohols (Nabais, 2008). While this study did not go into the composition of the wood, many of the compounds found would still be fully present in the residuals as they are not part of the oil that Nelixia extracts.

While some information was gained from this research, the articles reviewed still only allowed a preliminary look into the actual chemical composition of the residuals. If Nelixia wanted a more accurate chemical composition, which would be advised if they want to pursue something outside of what the team investigated, the CEMIT laboratory at the National University in Paraguay could test the residuals, though it would probably be a collaborative effort between the lab and Nelixia occurring over several months (D. Burt, personal communication, April 6, 2022). This option would also need to be explored further in terms of information such as cost for Nelixia to know if pursuing it would be worthwhile.

Boiler

The initial site observation revealed the need for changes to be made in the current process of using the residuals as fuel. The team therefore researched boilers in an attempt to suggest improvements to either the boiler or the burning process. Two articles were obtained for this purpose.

The first journal research gave extra information on the usage of biofuels around the world. The most commercialized use of biomass is pellets because it is easy to create dense, high-energy pellets that are easy to transport (Islas et al., 2019). The pellets can also be loaded automatically into the boiler, improving the process by adding a more consistent fuel flow and reducing the potential danger to the boiler operator. It was also found that carbonizing the wood residuals by roasting the residuals anaerobically raised the pellet's energy density by 25-30% (Islas et al., 2019).

The second journal discussed the effects of the geometric shape of the briquette or pellet on its burning efficiency. This article found that briquettes could burn up to 50% longer than pellets (Kraszkiewicz, 2022). This means it would be more efficient when hand-loading fuel, making it much easier to maintain a steady temperature and pressure without an added automation process.

Since the two methods of biofuel were found to be somewhat equal depending on the machinery used, further research was done to find different processes to load the fuel. One way was a hopper system which drops pellets into the boiler automatically based on the temperature and pressure (BM Engineering, n.d.). Another was an Archimedes' screw design that would automatically load the fuel – either pellets or raw residuals – from the fuel pile (Rorres, 2000). This would be very similar to the loading process already used by the Nelixia plant. The combination of this information showed that both briquettes and pellets are viable options and that selecting between the two would be dependent on how much Nelixia would like to invest in this process.

3.2: Field Research

One of the most important aspects of achieving the team's project goal was conducting semi-structured interviews. In almost all of our interviews, there was an overwhelming response to use the palo santo residual as a source of low cost biofuel, with secondary responses involving fertilizer and compost material. The information from these interviews was implemented into the team's methods and experimental designs.

The team's first interviews were with a group of Nelixia operators. The team wanted to get a firsthand perspective of what it was like to work with the residuals every day and how the residuals impacted their daily work. It was through these informants that the team learned of the 75% eucalyptus to 25% palo santo residual ratio fueling the factory's boiler.

Upon learning about how Nelixia operators use the residuals to maintain their boiler, the team moved on to our second group of interviews with the field experts. These field experts included two Nelixia engineers, as well as an expert in working with biofuels. These were the interviews where the team learned of some of the potential alternative uses for palo santo, including insect repellents and fertilizer. The team also learned from this group of interviews about the importance of the physical form of the palo santo residuals.

After finding this out the group began the final set of interviews with potential clients. These interviewees included an engineer at Cerámica Mazarrón factory – located a few kilometers away from Nelixia – an engineer at the Iris mosquito spirals factory located just outside of Asunción. The team was also given the opportunity to tour their factories. In these tours, the team got to see the current methods used by the clients and exactly where palo santo residuals could get introduced into the process. Our counterpart accompanied the team during these tours. This opened the lines of communication between Nelixia and the two potential clients, therefore cultivating a working business relationship between the companies. A brief breakdown of the information acquired from the interviews and tours with these companies is shown in Table 3.1.

Table 3.1
Comparison Between Potential Buyers

Company	Material	% Humidity	Distance (in km)	Quantity	Price
Cerámicas Mazarrón	Asserín	10	4	All	<₲250/kg
Iris	Aserrín	5 without penalty, 12 maximum	65	Limited (packed in big bags)	Unknown

3.3: Heat Capacity

The coffee cup calorimetry, used to find the experimental heat capacity of the residuals, resulted in high values, averaging 13.4 J/K over 8 trials. Based on Radmanović et al. (2014), this heat capacity was very high as it should not exceed 4 J/K. This deviation outside the normal range was marked as an experimental error from lack of proper materials to carry out the experiment. With the required materials and equipment, this experiment could be repeated to give a more accurate set of results. Further data and experimental set up can be found in Appendix G.

3.4: Safety

During the team’s time at the factory, we identified three major safety concerns: the large increase in temperature and size of the flames in the boiler when residuals are added, the proximity of the boiler to the residual pile, and the possible buildup of methane in the center of the residual pile due to an anaerobic environment. The first safety concern was observed when a Nelixia operator added residuals to the boiler. Upon contact with the fire, the flames nearly doubled in size, which created a large flux of heat. When asked about in an interview, it was confirmed that there was a potential danger to the worker running the boiler if they were untrained (anonymous Nelixia employee, personal communication, March 30, 2022).

The second safety hazard the team identified was the location of the residual piles. We found that almost 500 tons of the wood residuals were stored within twenty meters of the boiler. This creates concern as the piles can be very dry and flammable, and because the boiler is putting off embers every time wood is thrown in. This information gave us necessary insight to inform Nelixia that removing these residuals is a more urgent matter than they previously thought because these piles are not only a waste of space but also a safety concern.

The final problem is the likely buildup of methane in the center of the piles of residuals. One of the people we interviewed indicated that methane could build up within the piles because the center of the piles would create an anaerobic (oxygen-free) environment (anonymous bioenergy expert, personal communication, April 7, 2022). This creates an extreme safety concern due to the piles’ proximity to the boiler. We discovered in a study of birch wood chips that up to 6% of carbon in the palo santo wood could be converted into methane (Whittaker et al., 2016). This means that several tons of methane have likely been produced in these piles over the past year and a half. This gave the team the ability to give better, more accurate suggestions for the Nelixia plant.

After analyzing these safety concerns, it was evident to the team that the residual accumulation presented a potentially dangerous working environment for the factory employees. This prompted the team to begin our briquette experiment in the hopes of being able to address these concerns. The goal of creating these prototypes was to begin to mitigate the residual accumulation while simultaneously resolving safety concerns around the boiler.

3.5: Briquettes

Through the process of the experiments of creating and testing the calorific content of these briquettes, the team gained a better understanding of two things: what binders are the best for forming a full (eventually up to 75mm, 200 mm long (IndiaMART, 2022c)) briquette and what binder and briquette shape burned the best. This information could be useful in selecting a binder (either one that was tested or a new binder that combines beneficial characteristics of several tested binders for the actual briquettes made.

Making the Briquettes

The team initially attempted to make briquettes using either no binder, water for a binder, or oil for a binder. Because these attempts resulted in structurally poor briquettes, the team decided to use dry ingredients mixed with water for the binder. Based on literature findings and interviews, flour (specifically manioc starch), glycerol, starch, algae, and molasses were found to be common binders for wood briquettes (Obi et al., 2022), and it was determined that gluttonous materials would be preferred (anonymous bioenergy expert, personal communication, April 7, 2022).

From this information and the availability of raw materials, the team tried using bread flour, a form of whole wheat flour with a high (13-14%) gluten content (Alfaro, 2021); cornstarch; sugar; cracker meal, which is crushed cracker and contains enriched whole wheat flour, milk, and sugar (Gourmet Sleuth, n.d.); white flour (also referred to as all-purpose flour), a form of whole wheat flour with a medium (12%) gluten content (Alfaro, 2021); whole wheat flour, which has “more fiber and other nutrients than all-purpose flour” (Alfaro, 2021, Whole wheat flour section); and manioc starch,

Each binder was mixed with residuals as described in Appendix B. The general process used is depicted in Figure 3.1, and the resulting observations from making the briquettes is provided in Table B2 in Appendix B.

Figure 3.1

Team Members Making Briquette Prototypes

Note. These images show the basic process of how the team made our briquettes. All the images depict a briquette made with all-purpose flour as a binder. Photos taken by Sofi Murray.

The briquettes were then left to dry. They primarily dried indoors as opposed to in the sun as it was rainy during the weeks when they were made, so they could not be left outside. The earliest briquettes dried for a total of 22 days with the latest ones drying 13 days. The team noticed that the briquettes were still not dry, so we decided to dry the remaining briquettes using a gas oven and a toaster oven.

Out of all the briquette mixtures, the only ones that could stay molded in one 25 cm piece were the flour mixtures and the cracker meal. Both of these mixtures hardened well and could be viable choices to create briquettes in the future. All of the mixtures can be found in Table B1 in Appendix B.

Burning the Briquettes

The purpose of burning the briquettes was to qualitatively measure how they would serve as a fuel source. The first type of briquette that we burnt were the ones made with vegetable oil as a binder. These briquettes were able to sustain a flame the longest and also ignited the easiest. The other types of briquettes did not burn nearly as well as the vegetable oil ones. Even while continuously blowing on the fire to add ample supply of oxygen and adding plenty of kindling, none of the other types were able to sustain any type of flame. A table describing the burning qualities of each briquette can be found in Appendix C.

While attempting to light the non-oil types of briquettes, the team noticed water vapor emitting from them. This indicated that there was still water inside and that the briquettes were not completely dry. Before attempting to burn them again, the team dried them using a conventional gas oven and a toaster oven. The cracker meal briquettes (and two whole wheat flour ones) were dried for one hour at 110℃ in the toaster oven, the manioc starches were dried in the oven at 275℃ for one hour and twenty minutes, and all the other kinds were dried in the oven at 250℃ for thirty minutes. After the drying process, the team burnt the briquettes in the Nelixia factory boiler. When added, there was no increase in size or temperature to the flames of the boiler, and all of the briquettes were able to burn very easily.

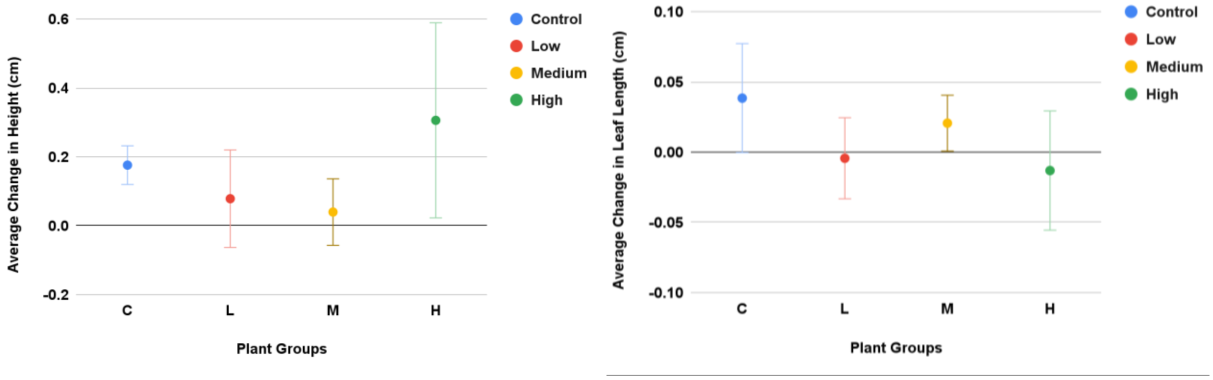
3.6: Plants

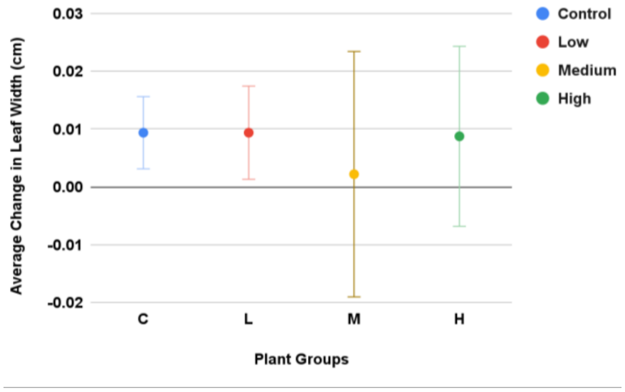
The purpose of this experiment was to analyze how palo santo impacts the growth of plants when used as a component in fertilizer and mulch, though the data was inconclusive. Looking only at the raw data and at the qualitative data obtained through comparing the photos (Appendix D), the group could tell that there was very little change in any group in the quantitative and qualitative data. However, the growth per day was still calculated per plant (as seen in Appendix D) so that the averages and standard deviations of each individual plant and each plant group could be determined.

The averages and standard deviations for the groups were the main source of comparison, allowing us to see if there actually was any difference between plant groups that went unnoticed looking just at raw data or at an individual plant's growth. Graphs showing these values for the three quantitative growth measurements are shown below in Figure 3.2.

Figure 3.2

Average Change in Height, Leaf Length and Width of the Groups of Carob Plants





Note. Each point in the graphs represents the daily average change of one group. The top left graph is for the change in height, the top right graph is the change in leaf length, and the bottom graph is the change in leaf width. The added error bars are equivalent to the calculated standard deviation of each group. As shown in the legend at the top right of each graph, blue is the control group, red is the low palo santo group, yellow is the medium palo santo group, and green is the high palo santo group.

In all of the graphs, the error bars overlap between the four groups, which means that no group experienced a significantly different growth rate than the other groups. There was also no noticeable trend for any of the measurements, let alone one common trend between all four measurements. While the results of this experiment concluded that there was no significant difference in growth, because the experiment was conducted over such a short period of time, this is not enough to accurately determine if the residuals have any effect on plant growth.

3.7: Compost

The final scientific experiment conducted was used to observe how the residuals could be broken down, thus determining if it could be used as compost. One observation that appeared is that all the bottles appeared dark due to the autoxidation of the residuals upon exposure to air. During the April 21st visit, it was noticed that there was minimal condensation on the bottles, implying the decrease of humidity, so water was added to the composts. The bottles were also shaken during this visit to maximize air throughout the bottle. Aside from that, though, there were no noticeable changes in the bottles, therefore giving no evidence of composting in a short period of time. That meant that no significant difference was found in the decomposition rate of any mixture, though because of the short time frame of this test, the experiment was inconclusive.

3.8: Cost Analysis

The different techniques for reducing their residual accumulation required the following startup and maintenance costs.

- Creating a self-sustaining biofuel such as briquettes or pellets would have a large start-up cost for their respective machines but would require less labor over a long period of time and would likely not require an intensive drying system (just a tarp or shed). They would also save money on eucalyptus.
- Selling residuals to Iris would require an intensive dryer system (an industrial dryer) to dry the residuals to 5% humidity, a grinder to process the residuals into a finer sawdust, bags

to load the sawdust into, the labor to complete all of those steps, and transport for the 65 km to the Iris factory.

- Selling the residuals to Cerámica Mazarrón would also require an intensive dryer system (an industrial dryer), but the residuals would only need to go down to 10% and they would only need to pay to transport the residuals 5 km.
- Selling the residuals as a mulch would have no costs other than the transport.
- Selling the residuals as a compost would require Nelixia to buy worms or microorganisms and to pay for the labor of turning the compost. Transportation would also be needed

A more in-depth cost analysis can be found in Appendix F.

3.9: Recommendations

As a group we recommend:

- Creating a self-sustainable biofuel in the form of briquettes or pellets with suggestions from the cost analysis on prices for presses;
- Selling residuals to the two companies, Cerámica Mazarrón and Iris, while meeting their humidity requirements by drying them; and
- Further testing of mulch and compost and searching for potential clients who would wish to utilize the residuals.

Our recommendations are organized based on what the team recommends as the most viable option for an alternative use for palo santo residuals, to the least viable, based on our understanding of the sponsor's thoughts and our findings.

Fuel Sources

Palo santo is considered a good fuel source for its high density, so a prime option is to utilize it as a fuel source on the factory grounds. Having the fuel source in the form of briquettes and pellets would both require some drying technique, which would add to Nelixia's costs, outlined in Appendix F.

Briquettes. Of the two types of fuel, briquettes seem to be the most beneficial, effective, and feasible. There are many benefits to the briquettes, one of which is that creating briquettes gives two avenues to get rid of the residuals – using the briquettes at Nelixia or selling them to the dairy plant on the grounds of the Escuela Agrícola – and since both of these could be explored by using the exact same process, making briquettes could amplify the net profit while increasing the rate at which the residual is removed from Nelixia's grounds.

Pellets. Pellets are also a very feasible option because the use of them would almost be the middle ground between the use of briquettes and only burning the sawdust. One of the main advantages of converting sawdust to pellets is that the process of fueling the boiler could be automated. Potential sales are also an advantage of the use of pellets. The dairy plant has already expressed the need for biofuel for its boiler. The factory could also likely find customers in the local area that have a similar need. The negatives of this are that the plant would need to buy a dryer, a hopper system, and probably a new boiler that will run on the hopper system.

Selling to Potential Buyers

Selling to the two identified potential buyers – Cerámica Mazarrón and Iris – is a viable option for Nelixia to consider as well. Because both buyers expressed a desire for dry sawdust, a dryer would have to be purchased for these options. An industrial dryer would be required, the most expensive of the drying techniques, to reach the desired humidity. An in-depth feasibility study would be needed to see if the cost of drying and transportation (along with any other expenses) would be worthwhile for Nelixia.

The Cerámica Mazarrón factory is one of the largest industrial plants in all of Paraguay, and is located just a few kilometers away from Nelixia. The factory fuels all of their machinery with low cost biofuel, specifically with wood from eucalyptus trees and other types of timber. The team interviewed an anonymous Cerámica Mazarrón representative who expressed interest in buying the palo santo residuals outright from Nelixia, so long as the residual piles were dried. Based on the cost analysis of initial investment as well as the fact that the physical form of the residuals will not need to be changed, it is highly beneficial for Nelixia and Cerámica Mazarrón to form a long term business relationship. Mazarrón exclusively expressed interest in buying large quantities of residuals at a time, which could eliminate the residuals immediately; however, the factory would have to wait until a large amount of residuals accumulated again to make another sale to the factory. If Mazarrón were to be pursued at all, Nelixia should sell a majority of the current residuals to Mazarrón as soon as they can get the residuals dry enough, and then move on to one of the other suggested results.

Iris is a factory that produces spirals that repel mosquitoes when burned. They are looking specifically for palo santo wood for the properties of the oil inside as an insecticide. Unlike Cerámica Mazarrón, Iris is interested in buying smaller amounts of residuals over a more continuous time frame. This would allow for Nelixia to keep leftover residuals to either be used as fuel or to explore other alternative uses. Another advantage to selling to Iris is that the raw material used by Iris's factory is sawdust, so Nelixia has no need to change the form of the residuals to sell them. The main disadvantage with Iris, especially when compared to the Cerámica Mazarrón factory, is therefore the larger transport distance. Between the two communities where the factories lie, there is over 60 km of distance to travel and to transport the residuals, which would likely add a significant amount to the costs. Regardless of the advantages and disadvantages for both companies, we would still recommend implementing a feasibility study for both companies to determine more accurate costs.

Mulch/Fertilizer/Compost

Of the options considered, using the residuals for fertilizer, composting, or mulch would be the least recommended. These options were initially considered as something that could be used by the Escuela Agricola, which would be beneficial given the close proximity and the existing relationship, but we found early on that the school was not interested (anonymous school representative, personal communication, March 28, 2022). These options were still tested since they were mentioned in several interviews, but since the school is not interested, another consumer would need to be identified, providing the first obstacle for these options. All of our results for the two experiments concerning these options (the plant experiment and the composting experiment) yielded inconclusive data as well, so while the residuals could work to promote plant growth, we have no hard evidence to support that. Therefore, more testing would be needed, either through continuing/repeating our experimentation or paying ₲1 million for an organic fertilizer test through Biosollo (D. Burt, personal communication, April 6, 2022).

3.10 Conclusion

The almost 500 tons of residual accumulation on the Nelixia property have the potential to be used for many different purposes. Based on the results of our research, the best potential use that the Nelixia company could implement to reduce residual accumulation is to use them as biofuel, specifically in the form of briquettes, to power the factory boiler. The team conducted technical experiments to determine how the briquettes would act as a biofuel, as well as for alternative uses such as a mulch and compost additive. Many of these experiments yielded inconclusive results due to time constraints, so it is recommended that they either be repeated or continued to yield more accurate results.

The team was also able to identify a market that Nelixia could sell their residual piles to. Under specific humidity conditions, Cerámica Mazarrón and Iris have expressed interest in buying the residual piles outright. Cerámica Mazarrón has interest in using them as a fuel source while Iris has interest in using them to create their mosquito spirals.

Using the residuals to fuel the Nelixia boiler as well as selling them to an outside company have potential to generate a net profit for the Nelixia factory. To make a more accurate decision on what would be the most profitable, this project could be continued by implementing a more in depth cost analysis that include feasibility studies for each option, as well as continuing the team's initial experiments.

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Appendix A: Interview Materials

Verbal Interview Consent Script

As a group of students from Worcester Polytechnic Institute (WPI) in Massachusetts, we would like to invite you to participate in an interview for our research to learn more about potential uses for palo santo residuals. The purpose of our research is to incorporate palo santo residuals into a profitable, carbon neutral commodity for the Nelixia factory. The kind of information that we aim to get from the interview is the impact of the palo santo residuals on your work at Nelixia. This interview also aims to get information on attempted uses for the residuals and the types of products you would like to see. We anticipate that the interview should take about 15 minutes.

This is a collaborative project between Nelixia, Fundación Paraguaya, and WPI, and your participation is greatly appreciated. Information from our project will be published in a publicly available academic document at the end of our term and we can share a copy of our results if you are interested. No names or identifying information will appear in any of the project reports or publications unless you give us consent to do so.

Your participation in this interview is completely voluntary and you may withdraw at any time. This also means that you can skip any questions that you want. Do you have any questions for us about this interview?

For more information about this research and the rights of research participants, you may contact us by email at gr-Oil-EssenceD22@wpi.edu.

Consentimiento Verbal para una Entrevista

Como grupo de estudiantes de Worcester Polytechnic Institute (WPI) de Massachusetts, le invitamos a participar de una entrevista para que, a través de nuestras investigaciones podamos aprender más sobre los usos potenciales de los residuales de palo santo. El propósito de nuestra investigación es determinar cual (o cuales) puede ser una disposición final de los residuales de palo santo que podrían beneficiar a la planta Nelixia. El tipo de información que esperamos recabar de esta entrevista incluye: entender cómo la acumulación de residuales de palo santo influye en el manejo diario de la planta Nelixia, interiorizarse sobre experiencias o intentos hasta la fecha de buscar una utilidad a los residuales de palo santo, y interiorizarse sobre posibles oportunidades de comercializar el residual de palo santo. Estimamos que la entrevista durará 15 minutos.

Esta es una colaboración entre Nelixia S.A. y WPI, y su participación en la misma es muy apreciada. Información sobre nuestro proyecto se publicará en un documento académico disponible en la base de datos de WPI al final del término académico, y podremos compartir una copia de nuestros resultados si a Usted le interesa. Ningún nombre, ni información brindada durante esta entrevista aparecerá en los documentos y publicaciones de nuestro proyecto, a menos que Ud. de permiso.

La participación de Ud. es totalmente voluntario, y puede dar por terminada la entrevista en cualquier momento de la misma. También puede abstenerse de responder a cualquier pregunta. ¿Tiene Ud. algunas preguntas para nosotros sobre la entrevista? Para más información sobre este proyecto y las derechos de los participantes, puede contactarnos por correo electrónico al: gr-Oil-EssenceD22@wpi.edu.

Appendix B: Making Briquettes

The briquettes were formed using several different binders to test their effectiveness as a binder as well as how they impact the calorific content. The binders tested were water, oil, bread flour, whole wheat flour, white flour, cornmeal, sugar, and cracker meal. Palo santo residuals were mixed with each binder and placed into an approximately 5 cm diameter, 0.3 m long piece of PVC.

The mixing was originally done by placing raw residual into the PVC pipe, adding an amount of binder, and stirring. This was done with the oil and water binders. However, it was then determined that it would be more beneficial to mix a known amount of binder and residual together and that the mixing should occur prior to adding the mixture to the PVC pipe.

Therefore, for the remaining six binders, the measured amounts of residual, binder, and water were added to a kitchen mixing bowl and mixed by hand. The general mixture consisted of 1.5 cups of residual, 0.5 cups of binder, and 0.5 cups of water. The measurements were done using designated clear solo cups with a sharpie mark at the halfway point since measuring cups, graduated cylinders, or other volumetric measuring devices could not be obtained.

After mixing, the consistency of the mixture was judged to determine if more residual, binder, or water needed to be added. If anything was needed, it was added and mixing was resumed, after which the same judgment was made. Once the consistency was satisfactory, the mixture was transported into the PVC pipe. A group of thin disks were then dispersed across the top of the residual mixture. A smaller PVC pipe was then held above the disks and pounded with a rock while the larger PVC pipe was held in place.

Once the residual mixture was as condensed as possible (as determined by no longer being able to hit the residual down farther), a downward pressure was applied to the smaller PVC while an upward pressure was applied to the larger PVC, allowing the residual, now a formed briquette, to emerge from the bottom. If the larger PVC pipe could not be moved without also moving the smaller PVC, the apparatus was inverted, and the smaller PVC pipe was then balanced on while the larger pipe was lowered. For these cases, the briquette was spotted as it emerged from the top of the PVC.

The briquettes were then left to dry. They primarily dried indoors as opposed to in the sun as it was rainy during the weeks when they were made, so they could not be left outside. A drier was not used as the only available drier would be the kitchen ovens, and the team did not want to use the oven because it ran the risk of either setting the briquettes on fire or, at the very least, creating a lot of smoke. The earliest briquettes dried for a total of 22 days with the latest ones drying 13 days.

Table B1

Composition of Briquettes

Binder	Binder amount	Residual amount
April 4		
Veggie oil	Not measured	Not measured
Water	Not measured	Not measured
April 7		
Bread flour	½ cup (water) / ½ taza	1.5 cup
Water	½ cup	1.5 cup
April 11		
Cornmeal	½ cup (water) / ½ cup	1.5 cup
^^	½ cup (water) / 1 cup	1.5 cup
Sugar	½ cup (water) / ½ cup	1.5 cup
Cracker meal	½ cup (water) / ½ cup	1.5 cup
April 12		
Cracker meal	½ cup (water) / ½ cup	1.5 cup
^	^	^
White flour	½ cup (water) / ½ cup	1.5 cup
^	½ cup (water) / 1 cup	1.5 cup
Whole wheat flour	½ cup (water) / ½ cup	1.5 cup
^	½ cup (water) / 1 cup	1.5 cup
Cracker meal	½ cup (water) / ½ cup	1 cup
April 26		
Manioc starch	⅓ cup (water) / ⅓ cup	⅓ cup

Note. The cup measurements were made using plastic cups with a sharpie line to indicate half cups. The manioc starch was made in a ratio such that, when dry, a 50% starch to 50% residual ratio would be obtained. This was done to get close to the 60% starch to 40% residual ratio used at Iris (anonymous Iris representative, personal communication, April 25, 2022).

Table B2

Briquette Production Findings and Observations

Binder	**Compressive Force**	**Briquette Length (cm)**	**Briquette Shape**	**Qualities Before Drying**	**Qualities After Drying**
Control (no binder)	High	N/A	N/A	Completely fell apart after removing from PVC	N/A
Water	High	5-10	Puck (short cylinder)	Solid, stayed in one piece	Crumbly and falling apart
Oil	High	5-10	Puck	Solid/firm	Crumbly and falling apart
Bread flour	Medium	15-20	Baguette shaped (Flattened cylinder with rounded ends)	Soft, floppy, moldable	Hard, stiff, and very durable
Cornstarch	High	N/A	N/A	Immediately fell apart after needing a lot of force to remove it from the PVC	N/A
Sugar	High	2-5	Pucks and spheres	A bit crumbly	Very crumbly (but less than water and oil)
Cracker meal	Low	20-25	Cylinder	Firm	Extremely hard, was dropped from 6 ft without any pieces breaking off
White flour	Medium	15-20	Baguette shaped	Soft and very moldable (can make a bird sculpture with it)	Hard, stiff, and very durable
Whole wheat flour	Medium	15-20	Baguette shaped	Soft, floppy, moldable	Hard, stiff, and very durable
Manioc starch	High	15-20	Cylinder	Soft, moldable, and airy	Hard, stiff, and durable

Note. The compressive force was categorized into low, medium, and high because the briquettes were manually compressed, and therefore, an exact force was not known. The lengths were also estimated, using the size of the large PVC (30 cm) as a reference.

Appendix C: Burning Briquettes

The purpose of burning the briquettes was to get an idea of their quality as a fuel source. The team constructed a small fire and relied on visual analysis and note taking to investigate how these briquettes would work as fuel. The team also videotaped the entire process so no details were missed and continued to add oxygen to the small fire. Due to time constraints, the team was able to burn only one of each type of briquette in the hand constructed fire, while the rest were burnt in the boiler at the Nelixia factory. The team relied on visual analysis, pictures, and videos during this process as well in order to capture any missed details.

Table C1

Briquette Burning Observations

Binder	**Observations, summary**
Oil	Burned very steadily for a long time
Water and oil	Let off an amount of steam despite drying for 3 weeks
Water	Fell apart easily, during process of adding to the fire
Sugar	Letting off large amounts of steam and hard to catch fire
Bread, whole wheat, and white flour	Let off a lot of steam when trying to burn, hard to ignite (results/observations were the same for all three types of wheat flour)
Cracker meal	Let off steam and burned a bit
All types in Nelixia boiler	Burned continuously (even when taken out of the boiler) and easily

Note. Top six rows are the results from burning in the small bonfire created by the team. Some briquette types were used entirely in the bonfire, so they were not present for the boiler burning. The ones in the boiler were bread flour, whole wheat flour, white flour, cracker meal, and manioc starch (which were not made in time for the bonfire).

Figure C1

Briquette Burning Experiment in the Bonfire

Note. The group set up a small fire with eucalyptus bark kindling in the bonfire area at the school. The picture on the left depicts one of the oil briquettes burning, and the entire burning session was recorded on a phone (seen in the picture on the right). Photos by Abigail Cummings (left) and Sofi Murray (right).

Figure C2

Briquettes Burning Experiment in the Nelixia Boiler

Note. The picture on the top left shows a variety of briquettes and the top right shows all manioc starch. The bottom row shows the briquettes zoomed in slightly. The first three on the bottom row are (from left to right) cracker meal, white flour, and whole wheat flour. Photos taken by Shannen Preble.

Appendix D: Fertilizer/Mulch Experiment

Four small trenches were dug in parallel with each trench dedicated to a group of plants. The desired amount of palo santo (no residual for control, four scoops – measured using a trowel – for low, eight scoops for medium, and twelve scoops for high) was then added to each trench and mixed with the soil. Once all the scoops were thoroughly mixed with the soil in each trench, the plants were planted, covering the roots with the soil-residual mixtures. An additional one, two, and three scoops of residuals were then added on top of the low, medium, and high groups respectively.

The height of each plant was then measured with a tape measure. The stems of the plants were straightened as much as possible and it was measured to the tip of the steam, getting the most accurate measurement possible. A picture of the plants was also taken, allowing quantitative data to be observed. At the next visit (April 7th), an additional quantitative measurement – leaf size – was added. One leaf was marked per plant, and the length and width of this plant was measured. All measurements were taken every Monday and Thursday between April 4th and April 22nd, with the exception of Thursday, April 14th (measured April 13th instead) and Thursday, April 21st (measured April 22nd).

After all the data was collected, the change per day in plant height, leaf length, and leaf width were calculated between each visit by getting the difference and dividing by the number of days between the measurements. The average and standard deviation of each daily growth was then found per plant as well as per group. These averages and standard deviations were used to see if there was a significant difference between groups for the collected quantitative data.

The qualitative data (leaf color, weed growth, wiltedness, etc.) was also compared between every visit to observe if those factors changed in a significantly different way in one group over another. Combining the results allowed the group to ascertain the effect, if any, that the residuals had on the early stages of plant growth.

Figure D1

Variables Used for Fertilizer/Mulch Carob Plants

	Plant 1 (left)	Plant 2	Plant 3	Plant 4 (right)
High Palo Santo	H1	H2	H3	H4
Medium Palo Santo	M1	M2	M3	M4
Low Palo Santo	L1	L2	L3	L4
No Palo Santo / Control	C1	C2	C3	C4

Note. The table shows the variables used for the carob plants, corresponding with the image on the right. The top of the picture goes with the top row and the left of the picture goes with the first column. Photo taken by Shannen Preble.

Table D1

Raw Data for the Measured Height (cm) of the Carob Plants

Date	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/4	17.5	32.7	13	21	28.5	16.5	27	31.5	18	28	32	22	29.5	18.5	34	15
4/7	17.5	35	14	23	29	18.5	29.5	30	18.5	28	32	23.5	29.5	22	35	23
4/11	17.5	35	14	23	29	18.5	29.5	30	18.5	28	32	25	30.5	22	35	25
4/13	18.5	35.5	15	23	29	19	30	30	18.5	27.5	32	25	31	23	35	25
4/18	18.5	35.5	15	23	29	18.5	30	30	18.5	27.5	32	25	31	23	35	26
4/22	19	35.5	16.5	23	29	18.5	30	30	18.5	27.5	32	25	31	24	35	26

Note. The M2 plant had a slight curve in it that formed following the April 11th visit. Other plants also had minor curves, but this was the only one that could not be fully straightened out, causing a decrease in height to occur between April 11th and April 13th.

Table D2

Raw Data for the Measured Leaf Lengths (cm) of the Carob Plants

Date	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/7	6	6.6	4.6	6.2	12.5	6	8.2	9.2	6.5	9.5	8	7.5	9.4	8.5	10.9	10.2
4/11	6	7	4.7	7.2	12.6	6.1	8.4	9.3	6.5	8.7	8.5	7.5	9.4	9.3	10.9	10.3
4/13	6	7	4.7	7.2	12.6	5.7	8.4	9.3	6.6	9.4	8.5	7.6	9.4	8.2	10.9	10.3
4/18	6	7.1	5.2	7.8	12.7	6	8.4	9.3	6.6	9.2	8.5	8.2	9.4	8.8	10.9	10.4
4/22	6	7.1	5.2	7.8	12.7	5.7	8.4	9.3	6.3	9.3	8.6	7.8	9.6	8.5	10.9	10.4

Note. Some of the leaves started to get withered, which reduced leaf length, though most of the discrepancies in leaf length changes were a result of the inaccurate measuring technique.

Table D3

Raw Data for the Measured Leaf Widths (cm) of the Carob Plants

Date	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/7	2	2.5	1.5	2	3.7	1.7	2.5	2.6	1.8	3	3.3	2.4	3	2.5	3.3	3
4/11	2	2.5	1.5	2	3.7	1.8	2.7	2.9	1.8	2.6	3.4	2.4	2.6	2.5	3.4	3
4/13	2.1	2.6	1.5	2.1	3.7	1.8	2.7	2.9	1.9	2.9	3	2.5	2.7	2.6	3.4	3.2
4/18	2.1	2.6	1.5	2.1	3.7	1.8	2.7	2.9	1.9	2.9	3.3	2.5	2.2	2.2	3.5	3.2
4/22	2.1	2.6	1.5	2.1	3.7	1.8	2.7	2.9	1.9	3	3.3	2.4	2.6	2.5	3.5	3.2

Table D4

Calculated Daily Change in Carob Plant Height (cm)

Intervals	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/4 - 4/7	0	0.767	0.33	0.67	0.17	0.67	0.83	-0.5	0.167	0	0	0.5	0	1.167	0.333	2.667
4/7 - 4/11	0	0	0	0	0	0	0	0	0	0	0	0.375	0.25	0	0	0.5
4/11 - 4/13	0.5	0.25	0.5	0	0	0.25	0.25	0	0	-0.25	0	0	0.25	0.5	0	0
4/13 - 4/18	0	0	0	0	0	-0.1	0	0	0	0	0	0	0	0	0	0.2
4/18 - 4/22	0.125	0	0.38	0	0	0	0	0	0	0	0	0	0	0.25	0	0
Mean	0.13	0.20	0.24	0.13	0.32	0.16	0.22	-0.10	0.03	-0.05	0	0.18	0.10	0.38	0.07	0.67
St. Dev.	0.217	0.33	0.23	0.30	0.07	0.31	0.36	0.224	0.07	0.11	0	0.24	0.14	0.48	0.15	1.13

Note. "St. Dev." is a shorthand used for standard deviation. Changes were calculated by subtracting measurements (Table D1), and the difference was divided by the number of days between visits.

Table D5

Calculated Daily Changes in Carob Plant Leaf Length (cm)

Intervals	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/7 - 4/11	0	0.1	0.03	0.25	0.03	0.025	0.05	0.025	0	-0.2	0.125	0	0	0.2	0	0.025
4/11 - 4/13	0	0	0	0	0	-0.2	0	0	0.05	0.35	0	0.05	0	-0.55	0	0
4/13 - 4/18	0	0.02	0.1	0.12	0.02	0.06	0	0	0	-0.04	0	0.12	0	0.12	0	0.02
4/18 - 4/22	0	0	0	0	0	-0.075	0	0	-0.075	0.025	0.025	-0.1	0.05	-0.075	0	0
Mean	0	0.03	0.03	0.093	0.01	-0.048	0.013	0.006	-0.006	0.034	0.038	0.09	0.01	-0.076	0	0.011
St. Dev.	0	0.048	0.05	0.119	0.01	0.117	0.025	0.013	0.052	0.231	0.060	0.09	0.03	0.336	0	0.013

Table D6

Calculated Daily Changes in Carob Plant Leaf Width (cm)

Intervals	C1	C2	C3	C4	L1	L2	L3	L4	M1	M2	M3	M4	H1	H2	H3	H4
4/7 - 4/11	0	0	0	0	0	0.025	0.05	0.075	0	-0.1	0.025	0	-0.1	0	0.025	0
4/11 - 4/13	0.05	0.05	0	0.05	0	0	0	0	0.05	0.15	-0.2	0.05	0.05	0.05	0	0.1
4/13 - 4/18	0	0	0	0	0	0	0	0	0	0	0.06	0	-0.1	-0.08	0.02	0
4/18 - 4/22	0	0	0	0	0	0	0	0	0	0.03	0	-0.03	0.1	0.075	0	0
Mean	0.013	0.013	0	0.013	0	0.006	0.013	0.019	0.013	0.02	-0.03	0.006	-0.01	0.011	0.011	0.03
Stand. Dev.	0.025	0.025	0	0.025	0	0.013	0.025	0.038	0.025	0.10	0.117	0.031	0.103	0.068	0.013	0.05

Table D7

Average and Standard Deviations in Growth Changes (cm) for Carob Plant Groups

	C Ave. | C St. Dev.	**L Ave. | L St. Dev.**	**M Ave. | M St. Dev.**	**H Ave. | H St. Dev.**
Plant Height	0.18 | 0.056	0.08 | 0.142	0.04 | 0.097	0.31 | 0.283
Leaf Length	0.038 | 0.039	-0.004 | 0.029	0.021 | 0.020	-0.013 | 0.042
Leaf Width	0.009 | 0.006	0.009 | 0.008	0.002 | 0.021	0.009 | 0.016

Note. These averages and standard deviations were the primary source of comparison and are shown in a graphical representation in Figure 3.2.

Appendix E: Compost

Four containers were set up for this experiment: a control with only palo santo residuals, one with residuals and worms, another with residuals and EM1, and a final container with worms, EM1, and residuals. The containers were created using 2 liter plastic bottles and cutting off the top of the bottle. One cup (plastic cup used as the measurement) of palo santo residuals was added to each container, and then the appropriate composting agent was added. The first container was the control, so it only contained residuals. A second cup of residuals was added to this container, though, to increase the overall volume of material in the container and make it match more closely with the experimental containers. Half a cup of activated EM-1, the brand of microorganisms used by the school, was added to the second container, and again, a second cup of residuals was added to increase volume. For the third container, a full cup of the worm mixture was added. Additional residuals were not included as the worm mixture added the desired volume of overall material. For the last container, a full cup of worms was added alongside half a cup of activated EM-1, again containing only one cup total of residuals.

Each container was then thoroughly mixed. After each container was set up, the top of the bottle was then inverted and placed back into the bottle, allowing only a small amount of air to access the mixtures. Qualitative data, consisting of noting observations and photographic evidence, was collected every Monday and Thursday (aside from the second observation, which occurred Wednesday instead of Thursday).

Alongside the qualitative analysis, the general conditions of the containers, specifically the humidity, were gauged each week to ensure the proper environment was being maintained.

Table E1

Compost bottles and their contents

Compost accelerant	**Amount**	**Residual amount**
Control / No accelerant	----------------------------------	2 cups
Microorganisms	½ cup	2 cups
Californian Worms	1 cup	1 cup
Mix / Both	½ cup microorganisms 1 cup worms	1 cup

Note. Cup measurements were made using a clear plastic cup with a sharpie line at the midpoint.

Figure E1

Pictures of the Compost Experiment Setup

Note. The picture on the left is eight days after the initiation of the experiment, and the right image is fifteen days after the start of the experiment (which was also the last day of the experiment). From left to right the bottles are worms, control, mix (worms and microorganisms), and microorganisms (specifically EM-1 brand). Photos taken by Sofi Murray.

Appendix F: Cost Analysis for Recommendations

The purpose of conducting a cost analysis was to help determine the economic feasibility of implementing the recommended techniques for Nelixia to mitigate their residual accumulation. To start the cost analysis, the team created a table (Table F1) organizing what materials and services would be necessary for each proposed solution. This information was organized to compare the different solutions.

It was found through an interview with an engineer at Nelixia that the plant buys its machines from India. For this reason the team did most of the research for prices on Indiamart. A website that sells a variety of items and machines. Using this website the team found the prices of the possible types of machinery Nelixia would use. In some cases such as some of the different dryers different websites were used to find prices such as Alibaba Express, Desertcart, and Amazon.

Making briquettes for Nelixia's boiler was the first option the team explored. An industrial briquette maker was found for ₲89 million[2], and it produces up to 800 kg of 75 mm diameter, 200 mm long briquettes every hour (IndiaMART, 2022c). In order to burn these briquettes, they would need to be dried. The team provides a table of the prices of the different forms of drying residuals in Appendix F (Table F2) and a table with the pros and cons for each drying method (Table F3). The distance that a product is transported to any customer is also necessary for cost analysis. For the briquettes, this would be the Escuela Agricola's dairy plant which is about 1 km away from Nelixia. This distance was estimated by the team during the many times the team walked from the Escuela Agricola to Nelixia. The next option we analyzed was the use of pellets in the boiler. An industrial biofuel pellet maker that processes up to 500 kg of biofuel per hour was found for ₲27 million (IndiaMART, 2022d). To run through the pellet machine, the residuals would likely need to be refined into a finer sawdust using a grinder. The team found one for ₲9 million (IndiaMART, 2022g). Another option that comes with using pellets is an automatic feeder to feed a boiler which was found for an additional ₲27 million (IndiaMART, 2022a). The pellets would require a similar drying and transportation system to the briquettes, thus making those costs nearly equivalent.

The third option was selling residuals to interested parties, specifically Cerámica Mazarrón – a nearby ceramics factory interested in the residual for a biofuel – and Iris, a mosquito repellent factory that uses palo santo residuals in mosquito spirals. Mazarrón would like to take all of the residuals at once with the only alteration being a reduction of humidity, reaching at most 10% humidity. This means Nelixia would only need to invest in drying (broken down in Appendix F) and transportation, which would be a mere 4 km. The price that Mazarrón would pay was also made clear (< ₲250/kg), allowing for a more complete analysis to be made (anonymous Mazarrón representative, personal communication, April 12).

Iris, on the other hand, would only be taking small amounts at a time, and they have more requirements. The highest percent humidity they would take is 12%, though to sell without penalty, 5% would need to be reached. Because the industrial scale dryers (which would be needed to get the required reduction in humidity for both Mazarrón and Iris) dry down to about 3% (IndiaMART, 2022b), though, the only difference this would create between the two selling options would be a potential increase in drying time. Nelixia would also need to purchase a grinder similar to the one mentioned for pellets, which was ₲9 million (IndiaMART, 2022g). After processing and drying

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[2] In Paraguay the currency used is called the Guaraní, with an exchange rate of $1 USD to ₲6,830.7 PYG (The Money Changer, 2022, May 2, 3:46 pm).

the residuals, Nelixia would need to bag them, which would cost about ₡1.000 per bag (IndiaMART, 2022i). While all of these would add some cost to Iris in a direct comparison to Mazarrón, the main discrepancy in expenses would come from the transportation as the residuals would be transported 65 km to Iris, a much farther distance than Mazarrón. As the price from Iris was not obtained and transportation cost is not known, a full comparison between the two cannot be made. However, because Iris specifically needs palo santo residuals while Mazarrón simply needs any type of sawdust, Iris would likely be willing to pay more, potentially balancing out the extra fees associated with that option.

The residuals were also considered as a source of fertilizer and mulch. In this option, the cost would primarily lie in the continued determination of whether or not the residuals are effective as fertilizer and mulch. This would either require the continuation and/or repetition of the experiment conducted by the team (which would mainly be a time cost for the company, though it would also include costs such as buying plant seeds) or the company could use a test such as the ₡1 million basic organic fertilizer test offered by Biosollo that looks into the chemical makeup of materials to determine if it would work as a fertilizer (D. Burt, personal communication, April 6, 2022). This option would also include a transportation fee, though since no potential buyers have been identified for fertilizer and/or mulch, the distance is unknown.

The final option considered was using the palo santo residuals as compost. As with the fertilizer/mulch, transportation would be needed for an unknown distance (due to the current lack of a buyer). This option also would need some decomposing agent; the team found two types – California worms and microorganisms – based on what is used by the Escuela Agricola for composting. The worms would cost ₡16.000/kg, and as the worms found come in 20 kg boxes, it would be a minimum cost of ₡320.000 (IndiaMART, 2022f). If the effective microorganisms (EM) were used, they would cost ₡71.000 for a liter (IndiaMART, 2022e). Because both of these components are dependent on the quantity needed (which is dependent on the ratio of each component used to residual and the total amount of residual used), though, the cost analysis for this option is very ambiguous.

To conclude the cost analysis, a very general comparison was made between each option in terms of the associated expenses. As several costs could not be included, the ranking is not definitive, though it can act as a general baseline for Nelixia to use in a later feasibility study. In the general ranking, making briquettes would have the highest initial cost. Pellets and Iris would fall into a similar price range underneath the cost of briquettes, and Mazarrón would follow. The fertilizer/mulch option would be the cheapest. Composting was not ranked because of the much higher level of uncertainty regarding the overall expenses.

Table F1

Overall Cost Analysis

Solution	Potential User	Needs	Prices	Source	Labor Necessary
Briquettes	Nelixia	Briquette press	₡89 million for 800 kg an hour of production	(IndiaMART, 2022c)	Medium
		Dryer	Table F2	N/A	
	Planta Lactea	Transportation	1 km	N/A	
Pellets	Nelixia	Pellet burner	₡27 Million	(IndiaMART, 2022a)	Low
		Pellet machine	₡27 Million 500 kg an hour	(IndiaMART, 2022d)	
		Dryer	Table F2	N/A	
	Planta Lactea	Transportation	1 km	N/A	
Sell to Interested Parties	Mazarrón	Transportation	4 km	N/A	Low
		Dryer - down to 10% humid	Table F2	N/A	
	Iris	Transportation	65 km	N/A	High
		Grinder	₡9 Million	(IndiaMART, 2022g)	
		Big bags	₡1000 per 1 ton bag	(IndiaMART, 2022i)	
		Dryer - down to 5% humid (or up to 12% w/ penalty)	Table F2	N/A	

Solution	Potential User	Needs	Prices	Source	Labor Necessary
Fertilizer / Mulch	Unknown	Transport	Unknown	N/A	Low
Compost	Unknown	California worms	₲16,000/kg (₲320,000 for 20 kg of worms)	(IndiaMART, 2022f)	Medium
		Effective Microorganism (EM) For Commercial, Grade	₲ 71,000/L	(IndiaMART, 2022e)	
		Transport	Unknown	N/A	

Note. Labor was estimated by the team and separated into low, medium, or high.

Table F2

Suggested Drying Practices and Their Estimated Prices

Type of drying	Potential Price	Specifications	Source
Industrial Dryer	₲54 million	Capacity/feed rate: custom Max Temp: 600 C Type: Rotary % Moisture: Unknown Delivery time: 6-8 months Location: India	(IndiaMART, 2022b)
	₲90 million	Capacity/feed rate: 5 kg/hr Max Temp: unknown Type: unknown % moisture: 3.5 Delivery time: Unknown Location: India	(IndiaMART, 2022j)
	₲53 million	Capacity/feed rate: 35 kg/hr Max Temp: unknown Type: Rotary % Moisture: Unknown Delivery time: 25 days	(Alibaba, 2022)

Type of drying	**Potential Price**	**Specifications**	**Source**
		Location: Uzbekistan	
Shed	₲9.9 million	Size: 3.5m x 3.81m x 2m Delivery time: 5-8 days Location: USA	(Desercart, 2022)
	₲11,235/m2 (₲56 million min)	Size: custom, 465 m2 min Delivery time: Unknown Location: India	(IndiaMART, 2022h)
Tarp Covering	12.2x18.3: ₲1.1 million 15.2x30.5: ₲2.1 million	Thickness: 5 mm Size: Multiple (12.2m x 18.3m and 15.2m x 30.5m best price per size) Material: Polyethylene Delivery time: 3 - 4 days	(Amazon, 2022b; Amazon, 2022a)
	12.2x18.3: ₲3.8 million	Thickness: 16 mm Size: Multiple (12.2m x 18.3m best price per size) Material: Polyethylene Delivery time: 3 - 4 days	(Amazon, 2022c)
	4x4: ₲103,000	Thickness: unknown Size: Multiple (4m x 4m best price per size) Material: unknown Delivery time: N/A (store in Asuncion)	(Lincoln, n.d.)
Sun	Free	N/A	N/A

Table F3

Pros and Cons of Drying Methods

Type of Drying	**Pros**	**Cons**
Industrial Dryer	- Definitely gets down to required % humidity - Might not take up a ton of space (1st listed definitely needs space, middle one prob same size as mixer at Nelixia, last one somewhere between the two) - Dries quickly	- Needs fuel - Would have regular expenses (fuel, maintenance, etc.) - Somewhat high initial cost
Shed	- Protects wood from elements - Dries enough for briquette or pellet - Just one upfront cost	- Would need multiple of first or large sizes in other two options - Takes up a lot of space - Not guaranteed to dry enough for Mazzarón and Iris - Would take longer to dry - High initial cost
Tarp	- Protects wood from elements - Dry enough for pellet and briquette - Wouldn’t take up more space than whatever is taken up by residuals at any given time - Low initial cost - Just one upfront payment	- Take longer to dry - Likely won't dry enough for Maazarrón or Iris - Likely need multiple
Sun	- Free - No changes needed	- Would not give desired humidity levels - Likely wouldn't be dry enough for briquette or pellet - Leaves open to the weather

Appendix G: Coffee Cup Calorimetry

The Coffee Cup Calorimetry began with measuring an amount of palo santo residual (around 8 grams for each trial) on a scale and then setting it aside to acclimate to the environment. Afterwards, hot water from a water fountain in the factory's kitchen was weighed out to about 150 grams or 150 milliliters and quickly covered with a piece of aluminum foil. Utilizing a thermometer borrowed from Nelixia, the initial temperature of the water was taken and recorded, and then the residuals were added to the water on a stir plate, and the team watched the fall in the water's temperature. Once the temperature steadied, that value was recorded and the thermometer was removed and set aside for a few minutes to take a reading of the ambient air. Following this reading, the values were imputed into a data table and, using Equation (1), the heat capacity was calculated.

$$(C_{water} \times \Delta T_w \times m_w) \ / \ (\Delta T_{residuals} \times m_r) = C_r \tag{1}$$

In the equation, C is specific heat capacity, m is the mass, and ΔT is the difference in temperature, shown in Equation (2). "water" and "w" subscripts are values related to the water. "residuals" and "r" subscripts are for residual values.

$$\Delta T = T_f - T_i \tag{2}$$

In Equation (2), T_f is the final temperature and T_i is the initial temperature.

Table G1

Calculated Results of the Coffee Cup Calorimetry Experiment

Heat capacity of the residuals (J/K)	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
	9.5	4.6	6.1	10.8	9.8	14.5	22.1	29.3

Appendix H: Fundación Paraguaya Deliverable

Resumen Ejecutivo para Fundación Paraguaya

Estudiantes de WPI en Colaboración con la empresa Nelixia

Introduccion:

Entre marzo y mayo 2022 un grupo de estudiantes de Worcester Polytechnic Institute de Massachusetts, EEUU (Abigail Cummings, Sofi Murray, Brandon Nieto, y Shannen Preble) colaboraron con la empresa Nelixia, de Benjamín Aceval, Paraguay en búsqueda de una solución para la disposición final de los residuos de palo santo remanentes de un proceso de extracción de esencia de palo santo (*Bulnesia sarmientoi).*

Próposito y Metas:

El equipo propuso varias opciones para la fábrica de Nelixia para mitigar la acumulación de aserrín destilado de palo santo con la meta de generar una ganancia neta de carbono neutral, además de crear un ambiente de trabajo más seguro. Nelixia estaba específicamente interesada en utilizar el residuo como biocombustible en su caldera, creando un sub meta de determinar cómo el residual podría ser mejorado como biocombustible, permitiendo así que el residual para autoabastecer la caldera. Sin embargo, incluso con esta meta más específico, la empresa todavía estaba interesada en explorar otras opciones potenciales permitiendo que la meta principal antes mencionada se mantuviera. Teniendo en cuenta tanto las metas principales como los secundarios, el equipo utilizó los siguientes tres objetivos:

1. Comprender la situación de la fábrica, específicamente en términos de las propiedades físicas del residuo
2. Entender y comunicar medidas de seguridad para almacenar residuales
3. Determinar la viabilidad de usos de los residuos, específicamente industrialización del residuo de palo santo como biocombustible para autoabastecer la caldera de Nelixia

Métodos:

Para lograr las metas y objetivos, el grupo usó varios métodos de ciencias sociales y ciencias. Los métodos siguientes usó durante los siete semanas:

1. Evaluación inicial del sitio - El equipo recorrió la fábrica de Nelixia y observó las propiedades físicas del residuo de palo santo.
2. Investigación de la literatura - Utilizando bases de datos como Google Académico y Ciencia Directa, el equipo investigó cuatro temas principales: microorganismos, composición química, calderas, y contenido calorífico del palo santo.
3. Entrevistas - El equipo realizó entrevistas con colaboradores de Nelixia para comprender la situación general, y luego se realizó entrevistas con expertos de campo (bioenergía e ingeniería de procesos) y clientes potenciales para medir la factibilidad de varios usos.
4. Calorimetría - El equipo utilizó un método simple de calorimetría para determinar la capacidad térmica específica de los residuos de palo santo.

5. Fabricar y quemar briquetas - El equipo hizo briquetas con una variedad de aglutinantes (ej. agua, aceite, y varios tipos de harina), y comprimió manualmente las briquetas utilizando trozos de PVC y una piedra. Luego, el equipo analizó cualitativamente cómo se quemaban las briquetas individuales a un pequeño fuego y filmando la quema.
6. Observación del efecto de aserrín para mulch - El equipo midió altura de plantas con cantidades variables de palo santo como mulch y enmienda de suelo, incluyendo la longitud de las hojas, y el ancho de las hojas.
7. Experimento de abono orgánico - Se agregaron lombrices californianas y EM-1 activado (una marca de microorganismos) a residuos de palo santo para observar cómo afectan la descomposición de los residuos.

Además de los métodos mencionados, el equipo tuvo reuniones con los consejeros (Prof. Curt Davis y Sra. Dorothy Burt) y la asesora de Nelixia, Ing. Andrea Horvath, cada semana para intercambiar ideas y obtener comentarios sobre los métodos y su progreso en el proyecto.

Resultados y Discusiones:

La metodología descrita arrojó los siguientes 5 resultados:

1. Acercamiento y datos concretos de compradores potenciales (los resultados concretos de estas conversaciones se muestran en la siguiente tabla)
2. Confirmación de alta capacidad calorífica
3. Fabricación de briquetas como potencial fuente de energía para Nelixia
4. Datos iniciales del uso del residual como abono

Cuadro H1

Información Sobre Dos Compradores Potenciales

Fábricas	**Material**	**% Humedad**	**Viaje (en km)**	**Cantidad**
Empresa 1	Asserín	10	4	Todo (Granal)
Empresa 2	Aserrín	5 sin penalizar, 12 máx	65	Limitado (empacado en “big bag”)

Recomendaciones:

Basándose en los hallazgos, el grupo recomienda lo siguiente:

1. Que Nelixia prueba briquetas de palo santo en su caldera
    a. Si se hace un exceso de briquetas, se puede vender el exceso a la planta láctea de la Escuela Agrícola
2. Llevar a cabo un estudio de factibilidad para determinar la viabilidad económica de secar el aserrín para luego vender a potencial compradores ya identificados
3. Realizar más pruebas del uso del residuo como abono orgánico y mulch