# *Exploring Opportunities to Valorize Argan Nut Waste in Israel*

*An Interactive Qualifying Project Submitted to the Faculty of*

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*In partial fulfillment of the requirements for the*

*Degree of Bachelor of Science*

*by*

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Report Submitted to:

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# Abstract

In southern Israel, Kibbutz Ketura is diversifying their agriculture by introducing argan trees, but the unutilized argan waste presents a problem. This project explored solutions for this waste through a literature review of argan and similar nuts' waste utilization. Possible products include kindling blocks, activated charcoal, biocomposites/plastics, active packaging, liquid biofuels, and large scale water treatment. Our recommendation for the kibbutz is that they prioritize the implementation of kindling blocks in the short term while striving to implement activated charcoal in the next 5-10 years after regulatory testing and authorization.

# Acknowledgements

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Lastly, we want to thank Worcester Polytechnic Institute for the opportunity to embark on this unique research opportunity as part of our Interactive Qualifying Project. While the group could not travel to the project site due to COVID-19, the remote program was run smoothly and was an overall success.

# Authorship

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| **1 Introduction** | Devin/River | All |
| **2 Background** | | |
| 2.1 Desert Agricultural Waste Management | Dawn/River | All |
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| 2.3 Finding Uses for Argan Waste | All | All |
| **3 Methods** | | |
| 3.1 Literature Review | Ezra/Dora | All |
| 3.2 Analysis of Potential Waste Solutions | River/Dawn/ Devin | All |
| **4 Results and Discussion** | | |
| 4.1 Easy to Implement | | |
| 4.1.1 Kindling Blocks | Dora | All |
| 4.2 Requires Further Research to Implement | | |
| 4.2.1 Activated Charcoal | Dawn | All |
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| 4.2.3 Active Packaging | Devin | All |
| 4.3 Unmarketable | | |
| 4.3.1 Liquid Biofuels | Dawn | All |
| 4.3.2 Large Scale Water Treatment | River | All |

| | | |
|---|---|---|
| 4.4 Recommendations | Dawn/Ezra | All |
| **5 Conclusions** | Dawn/River | Devin/Dora |

# Table of Contents

# Table of Figures

# Table of Tables

# 1. Introduction

Each year, Israel produces 7 million tons of solid waste, including agricultural waste, sludge, contaminated soil, and building debris (Nissim et al., 2005). The arid climate prevents the agricultural waste from decomposing, leading to buildup. As the waste accumulates, it is typically either burned or buried, leading to environmental pollution and the squandering of biomass that contains potentially valuable energy and materials. One instance of this is in Kibbutz Ketura, located in the Arava desert, where argan nut trees had recently been introduced for their valuable oil. The products of the argan nut that are currently marketable, the edible and cosmetic argan oils, only make up about 3% of the overall nut composition. The other 97% of the argan fruit does not have a viable use and is being treated as waste, with about two tons of argan nut shells (ANS) accumulated in large crates on Kibbutz Ketura at the time of the project.

In Morocco, the original home of the argan nut and where the majority of argan nuts come from, they feed the nut waste to goats. The kibbutz considered this solution to not be sustainable for them due to the large amount of waste compared to the small number of goats in the area. In addition, goat feed has a low market value, around $20-30 per 50 pound bag, and the kibbutz would like to make use of their waste in a more profitable way. The kibbutz considered utilizations such as fertilization and composting, but ultimately ruled them out because they would not produce valuable outputs that could be marketed elsewhere.

This project explored ways to valorize argan nut waste in Kibbutz Ketura. By determining the useful properties of the nut and conducting literature reviews, we identified six potential uses of the argan nut waste: kindling blocks, activated charcoal, biocomposites/plastics, active packaging, liquid biofuels, and large scale water treatment. We organized these solutions into three categories: easy to implement, requires further research to implement, and unmarketable. We conducted implementation analyses for current and future waste for the four most feasible solutions, which included all of the potential applications above except for liquid biofuels and large scale water treatment.

We delivered these potential solutions and implementation analyses to our sponsor for consideration and future use. By generating these waste solutions, we provided high-value solutions that could reduce or eliminate the buildup of argan waste in the Negev Desert. By valorizing argan nut “waste”, argan farming can continue to expand as a viable crop in arid regions and hopefully inspire other communities with similar wastes to look for valuable waste solutions.

# 2. Background

## 2.1 Desert Agricultural Waste Management

Wherever agriculture is prominent, agricultural waste is its natural consequence. Agricultural waste consists of any by-products from agricultural processes that do not have a viable use. This waste derives from sources such as farm animal byproducts, yard waste, and crop residues. Each type of waste requires a different method for management, which is vital to ensure that they do not end up as pollution (Israel Environment Bulletin, 1998).

When left untouched, agricultural waste accumulates quickly and can take up a problematic amount of space, as well as causing runoff which can harm local ecosystems. This built-up waste is a larger problem in the desert compared to other places, as the low moisture allows even organic materials to persist for long periods of time without breaking down. This is why it is important that proper management techniques are put into place to limit and utilize agricultural waste.

Agricultural waste management is vital to ensure that there aren't negative environmental impacts. Improper disposal of this waste, such as burning or burying, can lead to air, water, and soil pollution. As of 2019, burning at waste sites, including burning agricultural waste, accounted for 60% of Israel's recognized carcinogenic substance emissions into the air (*The Jerusalem Post*, 2018). To reduce harmful pollution from agricultural waste build-up, the Israeli government has stepped in by implementing waste management regulations nationwide. In 2015, the Ministry of Environmental Protection adopted a strategy to separate wet waste flow from dry waste coming from residents. Once the wet waste has been separated from the dry, it can be utilized in composting for agriculture. Additionally, the dry waste will break down much more easily and yield more valuable material (Volkan, 2015). A project funded by the EU LIFE program with the Ministries of the Environment and Interior created a centralized treatment plant for agricultural wastes and compost production to decrease water pollution and greenhouse gas emissions from agricultural waste piles. The Ministry of Environmental Protection also placed a ban on all burning of plant wastes and set a standard shredding disposal method that does not involve harmful gas emissions (*Agriculture: Sustainable Development Knowledge Platform*, 2011). In addition to the governmental efforts to reduce the negative environmental effects of agricultural waste, organizations in Israel and other countries with desert climates have found innovative ways to utilize the discarded portions of agricultural products that were once considered waste.

Israel produces a wide variety of agriculture, including citrus fruits, bananas, and melons (Leichman, 2018). Citrus fruits contain a variety of useful properties that lend to antibacterial, anti-inflammatory, anticancer, and neuroprotective effects. The wastes from these citrus fruits are currently being valorized as inputs for biofuels, soil additives through composting, and as components in food additives and pharmaceuticals (Sharma et al., 2017). Similarly, the rinds of melons have been proven to have anti-inflammatory, antiviral, and antidiabetic properties. While further studies need to be done to conclude the appropriate applications for this, there is strong potential in areas such as pharmaceuticals, cosmetology, and nutrition (Gómez-García et al., 2020). Bananas, another common fruit grown in Israel, have many waste byproducts, such as peels and leaves. The peels are being utilized in wastewater treatment plants, as a source of alkali in soap production, and biofuels, while the leaves can be used as food wrappers and substrate to grow produce such as oyster mushrooms (*Banana and Its by-Product Utilisation*, 2010). Similar to these agricultural waste solutions, Kibbutz Ketura is attempting to valorize the waste of their newly introduced argan trees.

## 2.2 Argan Trees

As Kibbutz Ketura looks to diversify their agricultural investments and income, they have shifted their focus from solely date farming to include argan trees as well. Argan is a crop with high potential value that has been shown to be lucrative in its homeland of Morocco. The argan tree, scientifically known as *Argania spinosa,* is a broadleaf evergreen tree that produces plum-size fruits with thick peels, sweet pericarp, and a tough nut in the middle (Missouri Botanical Garden, 2020). Since the tree originates from Morocco, which has a similar climate to that of southern Israel, argan trees adapt well to the extreme heat and aridity of Israel's deserts. According to our sponsor Nadav Solowey, who is pioneering the argan tree farm, argan trees consume only 30-50 liters of water per day, while other crops in the region can use up to 850 liters per day. Additionally, the argan trees can handle the large amounts of salinated water prominent in the Negev, which together with their water efficiency makes them more sustainable than the other crops in the region.

The argan tree is predominantly valued for the oil extracted from the nut. There are two types of oil that can be derived from this extraction process: one mainly used for cosmetics and one used in cooking. The cosmetic argan oil is cold pressed from the kernel, while the edible argan oil is made by roasting the kernel before pressing it (Charrouf & Guillaume, 2014). The cosmetic oil sells for around $30 for a four fluid ounce bottle ($253 per liter), while the edible oil sells for up to $300 per liter, making it the most expensive edible oil on the market (Vitality Extracts, 2021 & Ash, 2020). On a global scale, this market was estimated at $963 million in 2020 and is expected to reach $2.8 billion by 2027, making this a very promising market for the kibbutz to enter (Research and Markets, 2020). Given this growing market, the kibbutz has plans to scale up their farm. During the 2020 season the kibbutz had 800 trees, each producing 25 kg of fruit (12 kg ANS) per year, with plans to add 600 trees by the 2021 season. If they continue to add 600 trees per year, the kibbutz will produce 52,000 kg of ANS per year by 2026.

Despite the promising argan oil market, the oil extracted from the argan nut only makes up 3% of the total mass of the fruit. Of the remaining 97% of the biomass, Kibbutz Ketura has found that approximately 47% is dried fruit peel, 47% is the nut shell, and 3% is what remains of the kernel after the oil has been pressed out of it. The 97% of the argan fruit that is left after oil production is currently treated as waste. Kibbutz Ketura had these components analyzed for their chemical compositions, and the results provided by Nadav Solowey are summarized in Appendix A. Key findings from this report include that dry ANS are 30% lignin and 31% cellulose.

In Morocco, the nut shells and fruit peel are generally used as animal feed, and at the time of the project the kibbutz did the same. This was deemed unsustainable for their expanding operation because there will be too much waste relative to the amount of animals in the region. In addition, this feed has a low market value, around $20-30 per 50 lb bag, and the kibbutz would like to make use of their waste in a more profitable way. While there has been research regarding the potential of argan nut waste outside of animal feed, no products are currently in production commercially.

## 2.3 Finding Solutions for Argan Waste

There is emerging literature exploring promising and marketable ways to valorize similar nut waste, which may offer lessons for argan nut waste. In Iran, there is an abundance of pistachio shells that has previously been treated as waste. Attempts to transform this waste into value have shown that disregarded pistachio parts have the potential to produce bio-oil, fuel gas, and biochar from pyrolysis (Taghizadeh-Alisaraei et al., 2017). Another study showed that hazelnut shells can be used in biocomposites and epoxies to enhance mechanical and thermal properties (Kocaman & Ahmetli, 2020). Pecan nut shells possess antioxidant and food stabilizing properties, which have been utilized in active packaging (Moccia et al., 2020). Macadamia and walnut shells have been shown to have properties suitable for water filtration because they can remove metals, fats, oils, and other particles. (Wongcharee et al., 2017 and *Nutfilter® | Eden Products Ltd*, 2021). These waste solutions, although not involving argan nuts, can be analyzed further to guide our understanding of how to utilize argan nut waste on Kibbutz Ketura. Taking into consideration the priorities of the kibbutz, which include waste solutions that are environmentally friendly and economically viable, we explored six potential argan waste solutions that showed the most promise for the kibbutz.

**Kindling Blocks**

Artificial kindling blocks (also known as fuel logs or fire logs) are a popular alternative to wood burning, as they typically burn longer and hotter than a standard cord of wood. Any dry, organic material can be used for these blocks, which is an advantage in areas with small logging industries, although sawdust is generally the largest component of these blocks. All organic material contains lignin, which is the material that makes them woody. However, it can also act as a binder under pressure, making it useful to hold the blocks together. Sawdust and wood chips typically contain 20-40% lignin by mass, and dried ANS is composed of 30% lignin (see Appendix A), making them an appropriate substitution in these logs (Bernal-Lugo et al., 2019).

**Activated Charcoal**

Activated charcoal is produced from carbon rich substances, typically wood. Argan nuts are around 50% carbon, making them an excellent candidate for this use. To form activated charcoal, the desired starting substance undergoes carbonization at extreme heats and is then activated physically with water vapor or chemically with $H_3PO_4$ and NaOH. From this process activated charcoal can be used in water filtration, air purification, and as ingredients in beauty products. Activated charcoal sticks and filters are common household products that can be marketed worldwide, providing a variety of potential markets for the kibbutz to enter upon distribution (Rahib et al., 2019).

**Biocomposites**

Polymers such as polyethylene or polypropylene are commonly reinforced with synthetic materials, such as glass or carbon, to strengthen the structure of the plastic. Certain biological materials, known as bio-fillers, are candidates to replace synthetic fillers in some applications. The primary advantage of bio-fillers over synthetic options is that bio-fillers are more renewable and generally pose no health hazards. In one study, Elkhaoulani et al. (2013) estimated that about three tons of $CO_2$ emissions per ton of thermoplastic can be saved by replacing glass fibers with hemp. Bio-fillers also generally are low cost, low density, and have a high strength-to-weight ratio compared to the synthetic fillers (Essabir et al., 2015). ANS has shown promise when used as a bio-filler due to specific strong mechanical properties such as stiffness and strength (Essabir et al., 2013).

### Active Packaging

Active packaging is a type of packaging that provides added benefits beyond structural support, such as preservation by temperature regulation. ANS possesses antimicrobial properties, making argan-based composites uniquely suited for creating a film that can be used for active packaging (Lizard et al., 2017). By utilizing the powdered ANS as the raw material for making antimicrobial film, it could have a successful application in food packaging by being able to protect and preserve the contents much longer.

### Large Scale Water Treatment

Large scale water treatment is a multi-step process that can be used to treat wastewater to make it suitable for discharge. ANS is 31% cellulose (see Appendix A), which has been shown to be valuable in the adsorption of acids from industrial waste water (Bethke, 2018). As more nut waste components are being considered in large scale water treatment and filtration, ANS serves as a promising candidate moving forward.

### Liquid Biofuels

As fossil fuel resources begin to dwindle, the utilization of liquid biofuels has become more prominent. Biomass in which ethanol or methanol can be extracted serve as prime candidates for biofuel components. Because of this, many agricultural waste products are currently being researched as components in liquid biofuels. The composition of argan nuts is comparable to other nut wastes that have been used to create biofuels, making them an interesting prospect for further research.

# 3. Methods

This project explored ways to valorize argan nut waste. We conducted a thorough literature review to determine the properties of argan nut waste. Based on these properties, we investigated possible waste solutions and examined them against specific criteria to form implementation analyses.

## 3.1 Literature Review

Our primary research method to determine the properties of argan nuts, and ways to valorize them, was a review of relevant literature. The argan oil extraction process produces three types of waste: dry fruit peel, cracked nut shells, and crushed kernel dust. A chemical analysis of all three types of waste (see Appendix A) provided us with information about several key properties. We found any important mechanical, thermal, or chemical properties that were not included in that report through this literature review. We searched the WPI library and databases such as JSTOR, Scopus, and Web of Science for scientific articles and studies that provided the needed information. Using these databases, we combed through the material by highlighting some of the following keywords or key phrases: “<property> argan shells”, “argan peel <property>”, or “argan AND waste”. This search generated 10 relevant peer review articles. We also investigated the uses of argan and similar nut waste using the same method to the one mentioned above. We used the same databases but changed the keywords and phrases to match the difference in focus. Examples included “<carbonization> argan shells”, “nut wastes <biocomposites>”, or “argan nut water filtration”. This generated 20 articles that contained relevant information.

## 3.2 Analysis of Potential Waste Solutions

We divided the potential solutions we found in the literature review into three groups: easy to implement, requires further research to implement, and unmarketable (see Table 1). We looked at four major areas of concern when analyzing the feasibility of our solutions: equipment and costs, environmental impact, marketability, and further knowledge required.

Overall, we considered how feasible each option would be to implement using the criteria below. The first area of concern was equipment and materials required, including their respective costs. This included machinery, necessary chemicals or additives, packaging, and the overall cost of these. The second area of concern was the environmental impact. We examined what inputs were required for each system, and what waste streams, including physical waste, leftover chemicals, and emissions, exit the system. We then determined the net waste that would be produced or used by the process, when possible. If there was waste produced, we performed preliminary research into the difficulty of disposing of that waste. Thirdly, we analyzed the current potential market, the potential prices for the products when applicable, and how each solution would grow in the market as the amount of argan nut waste increases at Kibbutz Ketura. Finally, we evaluated how much more knowledge would be required to fully understand the waste solution. This included further research that could be conducted but was outside the scope of this project, experts that would need to be consulted or actively involved in the process, and further experimentation needed. We analyzed these criteria for each use to create implementation analyses.

# 4. Results and Discussion

Through a literature review, we researched and developed ideas that could be implemented to valorize the argan nut waste in Kibbutz Ketura or other organizations looking to enter the argan industry. We sorted these ideas into the following three implementation categories based on overall feasibility, as seen in Table 1:

1. Easy to Implement
2. Requires Further Research to Implement
3. Unmarketable

In this section, we present and analyze our findings from the literature review while analyzing the implementation potential for each waste solution. These analyses present information in the same structure: description of the product, review of the production processes, analyses of machinery and materials, additional costs, environmental impacts, marketability, potential knowledge gaps, and extra steps needed.

*Table 1: Implementation Categories for Each Potential Waste Solution Based on Overall Feasibility*

| **Easy to Implement** | **Requires Further Research** | **Unmarketable** |
| --- | --- | --- |
| Kindling Blocks | Activated Charcoal | Liquid Biofuels |
| | Biocomposites/Plastics | Large Scale Water Treatment |
| | Active Packaging | |

## 4.1 Easy to Implement

### 4.1.1 Kindling Blocks

One of the more straightforward possibilities for nut shell use would be making them into kindling blocks. There are two ways in which kindling blocks can be formed. The first way involves mixing the ANS with an adhesive in which the shells are then dried. In the second way, no adhesive is used and the lignin in the shell acts as a binder as the block is compressed into a mold. Lignin is the woody material in plants, and dried ANS is composed of 30% lignin by weight (see Appendix A). Despite these differences, both methods start by grinding or crushing the shells into smaller sizes so that they burn more evenly, which can be done using a universal cutting mill or other grinding device. The recommended brand for this is the Fritsch Pulverisette 19, which is priced online at $11,300-11,800. The overview of these two processes can be seen in Figure 1.

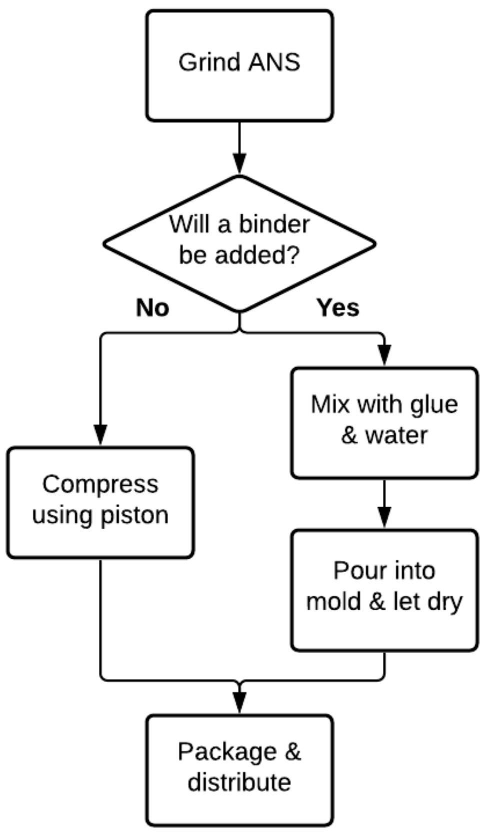


*Figure 1: Flow Diagram of Kindling Block Production Process*

In the kindling blocks production method that uses glue, the ANS is ground to between 0.5 and 1 millimeters in diameter (Babty et al., 2019). This ensures the highest thermal conductivity. The recommended adhesive is a powdered urea formaldehyde resin, which is an adhesive commonly used in wood-based composites. The blocks contain 50% shell particles, 25% powdered adhesive, and 25% water by mass. The ingredients can be mixed together using any common electric mixer, which the kibbutz may already have on site. After these are combined, the mixture can be poured into molds and left to dry at atmospheric conditions for three days.

The powdered shells can also be pressed into blocks without an added binder, in which case the lignin needs to be activated by applying pressure. While most companies do not explicitly disclose the amount of pressure used to make their logs, according to a representative of the BIO BLOCKS company (see table 2) their logs require 300,000 tons of pressure to compact. Their product uses sawdust; however, research has not been performed on how much pressure is required to make a log out of ANS dust. We recommend that the kibbutz arranges to test compaction at multiple pressures (100, 150, 200, 300 thousand tons) before purchasing a machine of their own, although the pressure required will vary based on the size of the block. The pressure is applied using piston compaction with a hydraulic press or eccentric press, where the ground up ANS are put into a thick metal sleeve and pressure is applied from one end using a piston according to a representative of Good Wood Logs. One press that could be used, the Redline 150 Ton Electric Hydraulic Shop Press, costs $11,000. The sleeves can be reused indefinitely. After that, the blocks are finished and should be packaged in airtight packaging for shipping.

*Table 2: Comparison of Fire Log Brands*

| Brand | Price Per Log | Number in Pack | Added Binder? | Size | Weight | Burn Time |
|---|---|---|---|---|---|---|
| Bio Blocks | $1 | 12 | No | 5″ x 11″ x 12″ | - | 4 hr |
| Good Wood | $12.5 | 4 | No | 16” long | 3.4 kg | 2+ hr |
| Duraflame | $3.33 | 9 | Yes | 16” long | 2 kg | 3 hr |
| Duraflame-renewable | $5 | 4 | Yes | 16” long | 2.7 kg | 4 hr |
| Pine Mountain | $4.65 | 6-9 | Yes | 16” long | - | 3 hr |
| Enviro Log | $5 | 6 | - | 11” long, 4” diameter | 2.3 kg | 3 hr |

Because most parts of Israel have little need for home heating, the blocks would most likely be marketed towards camping or outdoor cooking, or exported to similar markets elsewhere. Ketura is located in an area with plenty of outdoors activity but very little firewood available, creating a demand for products like this. Similar products on the market made from sawdust are generally priced around $10-$20 for a pack of 12 blocks, although there is considerable variation between brands, and brands that do not use glue or wax tend to be cheaper than ones that do. Table 2 shows a comparison between some of the common brands in the industry. They do not all have the same information available online, so not all fields can be compared directly. Within brands, most offer multiple options for burn times (2, 3, or 4 hours commonly) with the prices rising with the burn time. The burn time can be adjusted by increasing or decreasing the volume of the argan logs and will have to be determined experimentally. If all ANS produced by the kibbutz in the 2021 season is converted to kindling blocks of 2 kilograms, for example, the kibbutz could produce around 8,000 blocks. If each block is sold for approximately $3, the revenue would total $24,000. In 5 years, using current estimates, this could rise to 26,000 blocks and $78,000 per year. These products are typically sold in outdoors-type stores or online, so there is an existing market for the kibbutz to enter.

## 4.2 Requires Further Research to Implement

### 4.2.1 Activated Charcoal

Activated charcoal made from ANS contains properties suitable for water filtration, air purification, and beauty products. ANS that undergoes carbonization and is then activated can be used in any activated charcoal product or system, as seen in Figure 2. Before this carbonization process can be completed, ANS must first be ground up using a machine such as a universal cutting mill ($11,300-11,800). The ideal size to grind the ANS to varies depending on the specific pyrolysis process, but it is within a range of 3-5 millimeters. We picked two of the many available carbonization processes to evaluate for the Kibbutz, although they will require a more thorough evaluation once a decision has been made to move forward with this idea. The first process involves two stainless steel drums placed inside of each other, with the ANS placed within, and then a 4-5 hour burning process as shown in Figure 3 (*Living Web Farms,* 2013). The resulting charcoal from this process is about one third of the input weight and can be stored in sealed, air-tight containers for up to three years. The cost of these storage containers is as little as $50 for 70 gallon containers. This process is relatively new and has not been tested with ANS, so it is not yet clear what the optimal input diameter of the ANS would be. Wood sticks have been the most tested input materials, but the switch to argan nuts could necessitate different burning times and temperatures used to get the desired product. Despite these unknowns, this process is relatively simple, and with full-scale preliminary testing it could be implemented efficiently.

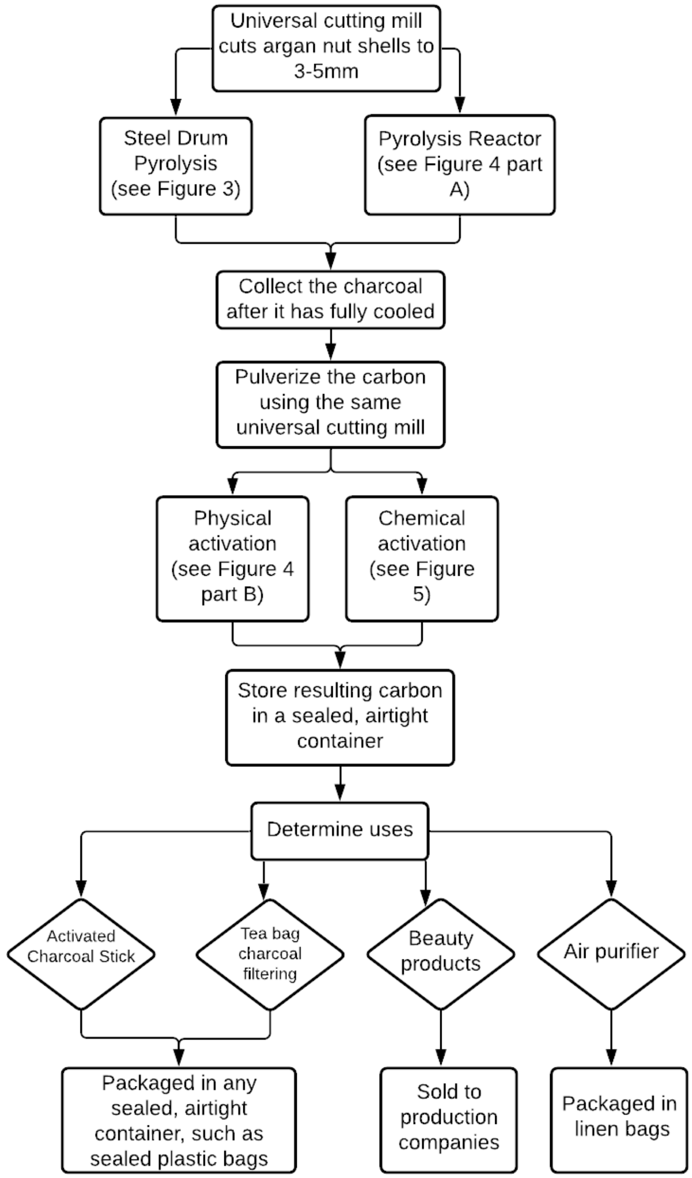


*Figure 2: Flow Diagram of the Overall Activated Charcoal Production and Dispersion Process*

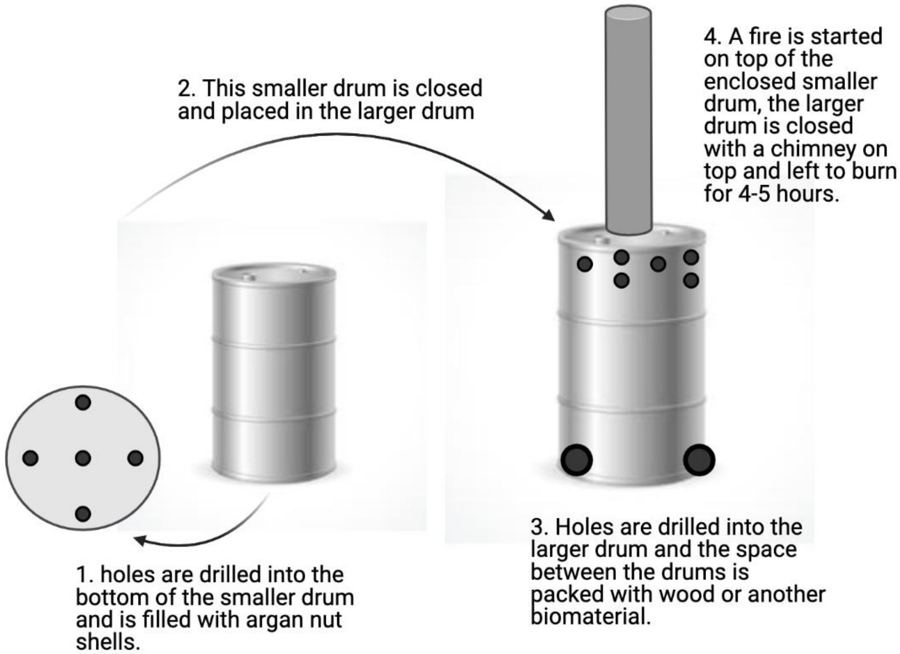


*Figure 3: Metal Drum Pyrolysis Setup*

In the second method, the dried argan nuts are run through a pyrolysis reactor in which the biomass is heated to 550℃ for 60 minutes under continuous nitrogen flow (60mL/min), seen in Figure 4 part a. (Zhou et al., 2018). The nitrogen flows through the reactor, expelling all carbon dioxide from the atmosphere. Some of the nitrogen is then absorbed into the resulting charcoal while the remainder is collected in the absorption bottle shown in Figure 4 part a. This can be disposed of by diluting it with tap water and washing it down the sink or even using it to water your plants to add extra nutrients. There are a variety of pyrolysis reactors available commercially, however the reactor depicted here involves a quartz boat and tube inside of a tube furnace. The tube furnace mechanism required for this reaction can cost between $4,000-15,000 depending on the size (*Nabertherm*, 2021). The resulting carbon from this process is about 45-50% of the input weight and can also be stored in a sealed, air-tight container for about three years. Both carbonization processes have the same end result, but there are notable differences. While the pyrolysis reactors are more expensive than the drums, which average around $700 per drum, the drums need to be replaced around every 10 runs, which could end up accumulating a higher cost, more waste, and additional transport required over time. In addition, the pyrolysis reactors are a more exact science, as the atmosphere under which the reaction can take place is controlled and the temperature can be maintained at a specific value, while the drums have room for variability. It is also worth noting that the burning inside the metal drums is designed to produce no smoke outside the set-up. This means that only water vapor and carbon dioxide are being dispersed into the atmosphere, making this an environmentally friendly clean burn. Both processes are also relatively quick, and the input sizes can be scaled up depending on the amount of argan nuts harvested.

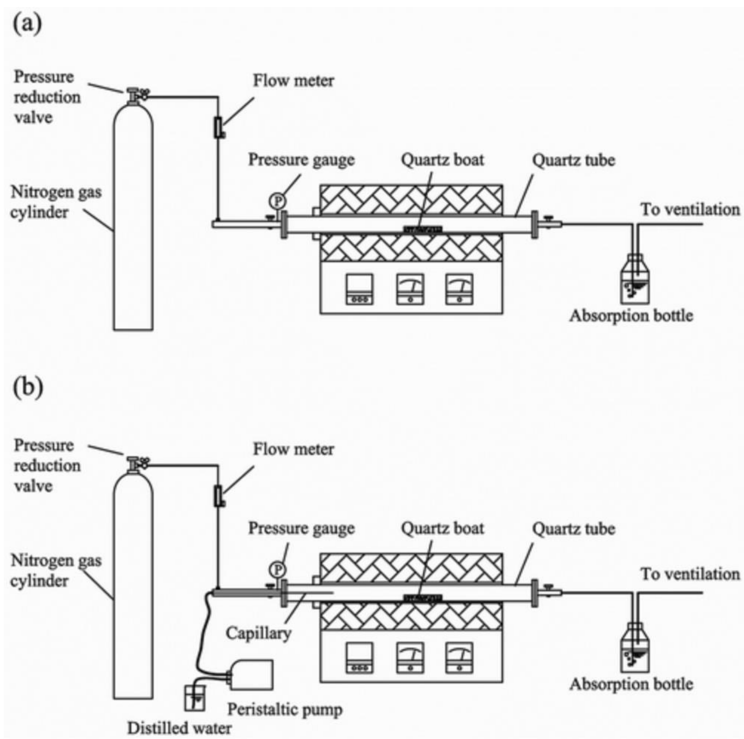


*Figure 4: Carbonization and Physical Activation Processes for Activated Charcoal, Adapted from Jiazhen Zhou et al. 2018*

Once carbonization is complete, there are two ways in which the resulting carbon can be activated: physically or chemically. The physical activation process involves steam in a nitrogen atmosphere, seen in Figure 4 part b (Zhou et al., 2018). The chemical activation process involves crushing the carbon up and making a slurry with $H_3PO_4$ and NaOH. The carbon can be crushed using the same universal cutting machine mentioned before, as long as it is cleaned between uses. This slurry is then dried, pyrolyzed for one hour under a nitrogen flow at 700℃, and then washed with water and dried at 120℃, shown in Figure 5 (Zbair et al., 2018). The water used to wash the carbon can be recollected with the acid in it and reconcentrated back to the necessary concentration to be used again, eliminating chemical waste. The resulting carbon from chemical activation has a greater absorption capacity, making it a more efficient filter. Conversely, the carbon resulting from physical activation has more uniform pore distribution, but a lower absorption capacity (Nowicki et al., 2010). Whichever method is chosen, this activated carbon can then be utilized as a water filter and purifier.

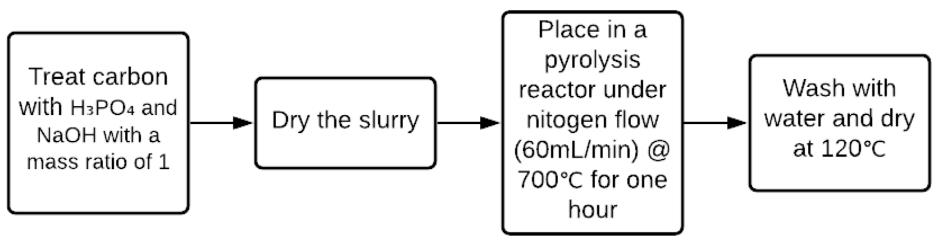


*Figure 5: Chemical Activation Process*

One way to use this product is through an activated charcoal stick which rests in a container of water and purifies the water within four hours. Every 2-3 weeks the stick should be boiled for 10 minutes to clean it, and it can then be reused in the exact same fashion, though after three months the stick should be replaced. Once the charcoal stick is used up it can be placed in a garden to biodegrade and help enhance the gardening soil. Activated charcoal sticks typically get their shape from the wood being burned, so the resulting carbon from the processes above would have to be molded into a stick shape, though the literature did not mention how this would be accomplished. The activated charcoal can also be kept as a loose powder and placed in tea bags and soaked in water, instead of being used as sticks. In addition to this, activated charcoal in any form can be left out, in linen bags for example, to adsorb odors from the air. The charcoal can be left outside in the sun for about an hour once a month to cleanse the pores, after which the charcoal can be reused. Similar to the charcoal sticks, when the charcoal bags are no longer adsorbing odors the charcoal inside of them can be placed in soil to help fertilize plants. Activated charcoal is also often used as an ingredient in beauty products, which presents an opportunity for the kibbutz to sell the raw materials to cosmetic companies elsewhere.

Activated charcoal products have the potential to be used on the Kibbutz, sold and marketed elsewhere, or the raw materials could be sold for processing elsewhere. Activated charcoal sticks are currently being marketed for around $5-$8 per stick, normally sold in packs of 4-6 sticks. These products would require air-tight packaging. Packaging costs vary, but can be as little as two cents per unit when bought in bulk. Activated charcoal for air purification already packaged in bags can be sold for around $5 per 200 ounce bag. Linen bags for air purification can be purchased in bulk for as little as 13 cents per unit (ULINE, 2021). Raw activated charcoal is commonly sold in a range between $800-3,000 per metric ton. With the projected number of trees for the end of this year, the kibbutz would have around 6.6 metric tons of activated charcoal produced per year. If the kibbutz continues to add 600 trees per year, as they did this year, in 5 years the kibbutz would be able to produce around 21 metric tons of activated charcoal per year. This would mean that in 5 years the kibbutz could produce around 210,000 activated charcoal sticks per year. If those sticks were sold for the higher price of $8, in 5 years the kibbutz could potentially make up to $1.68 million per year, assuming they only sell charcoal sticks. In 5 years, air purification bags could potentially make $510,000 per year.

Given the wide variety of uses for activated charcoal and the current demand for it in personal homes, there is a market for the potentially large amounts produced on the kibbutz. The market for activated charcoal is expected to grow to $3.7 billion by the year 2026 (Cision PR Newswire, 2020). It is expected that the market for activated charcoal as air purifiers could increase even more in the coming years, as the COVID-19 pandemic has heightened the public's concern about air quality. In addition to this, most activated charcoal production is done either in Asia or North America, leaving other areas of the world as potential untapped markets. While the production of activated charcoal is promising, it would require the purchasing of materials and thorough experimentation by the kibbutz before a suitable product is made. Further experimentation should be run on the steel drum pyrolysis mechanism to optimize the conditions. We would recommend consultations with outside experts to ensure the final product is safe for human consumption and to ensure the processes are running safely, which would factor into the overall cost. Chemists would be able to ensure the composition of the charcoal is not harmful and that the carbonization and activation processes are running correctly. Biologists and water purification experts could ensure that the activated charcoal is filtering correctly, and the water is clear of contaminants after filtration.

### 4.2.2 Biocomposites and Plastics

ANS has shown the potential to be a filler inside of a biocomposite. Biocomposite materials typically consist of a plastic polymer reinforced with a strong filler to enhance different characteristics, such as mechanical, thermal, and chemical properties. Following the steps laid out by Essabir et al. (2015), certain machinery and materials are needed to create an argan-based biocomposite. There are five primary materials needed: high-density polyethylene (HDPE), ANS, distilled water, sodium hydroxide, and acetic acid. The composite is produced in two steps: preparing the ANS powder and the formation of the composite. In the first step, the ANS is ground into microscopic particles using a universal cutting mill to an average diameter of 49 micrometers. It is kept in an aqueous sodium hydroxide solution with a concentration of 1.6 $mol{\cdot}L^{-1}$ for two days to strip away the oils and waxes that would limit the adhesion between the powder and the HDPE. After the ANS is taken out of the bath it is treated with acetic acid to neutralize any lingering sodium hydroxide, thoroughly washed with distilled water, and dried at 60℃ for one day. After the pre-processing of the ANS, the filler and polymer matrix can be compounded.

Shown in Figure 6 below, an extruder and optionally an injection molder are used for the compounding stage of the process. An extruder, shown in part (a) of Figure 6 below, is used to combine and mix the HDPE with the ANS; the materials are added through the feeders and are mixed and heated. The extruded biocomposite is then cooled in a water bath and turned into 2 mm pellets using a grinder. These biocomposite pellets can be stored as-is until the plastic is needed, and then can be utilized in a variety of ways. By changing the die inside the extruder, it can be used to create different materials like plastic film, piping, or plastic bags. The biocomposite pellets can also be used with an injection molding machine, shown in part (b) of Figure 6, which creates a product that can be used in a variety of applications. These molds can be shaped in any configuration needed. This entire process is summarized in Figure 7 below.

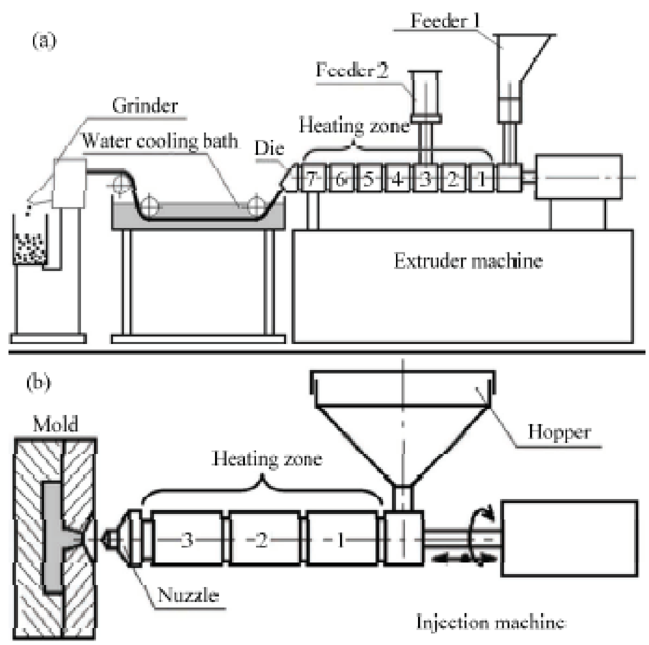


*Figure 6: Illustration of the Bio-composite Creation Process. Adapted from Essabir et al. (2015)*

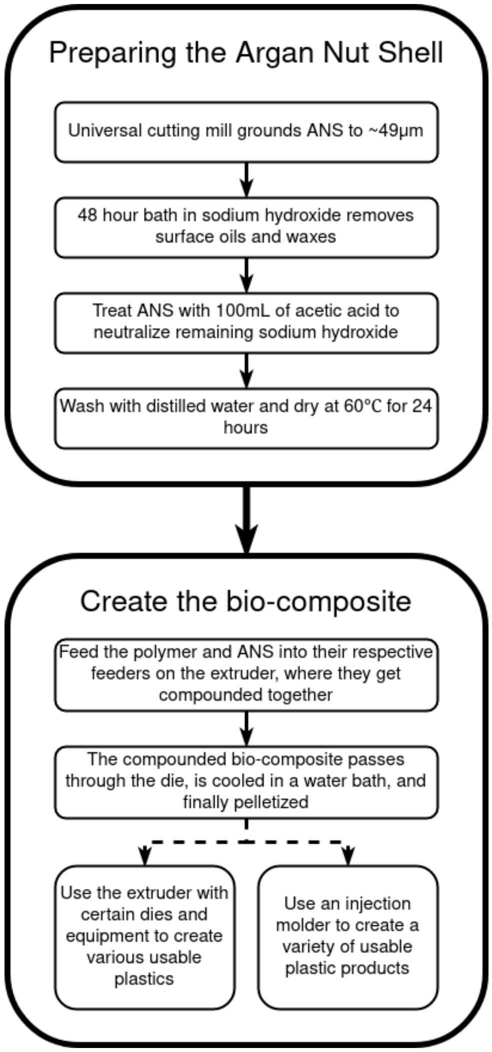


*Figure 7: Flow Diagram Showing an Overview of the Biocomposite Creation Process*

There are two main challenges when it comes to reinforcing plastic polymers with ANS: the hydrophilic characteristics of the nut shells, and the need for a uniform dispersion of the ANS powder inside of the polymer matrix. The former can be mitigated through chemical surface treatments, such as silanization or acetylation. The latter challenge can be prevented through careful use of the extruder, and proper research into both the optimal temperatures for the heating zones, and the ideal speed for the mixing inside of the machine. Essabir et al. (2015) provides certain values that can be used as starting values for testing. In their methods, the heating zones range from 170-180℃. The main screw in the extruder ran at 125 rpm, while the side screw that fed the ANS turned at a speed of 40 rpm. If the compounding is not properly executed, there is a risk that the ANS agglomerates inside of the polymer, weakening the structure of the biocomposite.

The bio-loaded plastic that is created through this process has applications across many fields. For the kibbutz, one of the primary potential uses of this biocomposite is in the active packaging field described in section 4.2.3. The material can also be sold outside of the kibbutz, or kept in-house for a variety of uses such as storage or food preservation. The composite can be kept in pellet form for easier storage, and then molded into any form needed using the extruder and injection molder.

Implementing this system also comes with certain drawbacks for the kibbutz that would have to be considered. There will be leftover chemicals that would need to be disposed of, as well as carbon dioxide emitted during the process, even though the emissions are of a far lesser magnitude compared to the synthetic fillers. The kibbutz would also have to purchase, and have plenty of space for, three separate pieces of large machinery which would be an estimated $50,000-75,000 investment dependent on specific machines acquired, along with continual purchases of the necessary chemicals and HDPE.

### 4.2.3 Active Packaging

The chemical properties of the ANS and powder can be utilized to produce active packaging material. Active packaging is a form of smart packaging that not only protects and secures the contents inside, but also performs other forms of maintenance, such as preserving the contents by regulating the temperature of the package. The chemical report showed that the argan shells and powder have reinforcing qualities seen in their polyhedral shaped microstructure and could be utilized in different forms such as the biocomposites mentioned above (Moumen et al., 2020). The shells, powder, and fruit peel also have antimicrobial and thermal insulating properties, which are beneficial properties to have in a packaging material when considering temperature regulation and cleanliness in food packaging.

An antimicrobial film can be produced by compounding the high strength characteristics of the shells and powder with a polymer such as polyethylene. This antimicrobial film could then have a valuable role in active food packaging, providing structural reinforcement as well as preservation and maintenance of the packaged food item. In active packaging tests, the shelf life of bread was extended multiple weeks by using a similar film that utilized oils as the alternative antimicrobial material (Van Dam, 2019). There are different polymers and compounding processes which can be used to produce an antimicrobial film, and an expert in compounding and film production could conduct different experiments to find which components are ideal for packaging. An example of a polyethylene compounding process can be seen below in Figure 8.

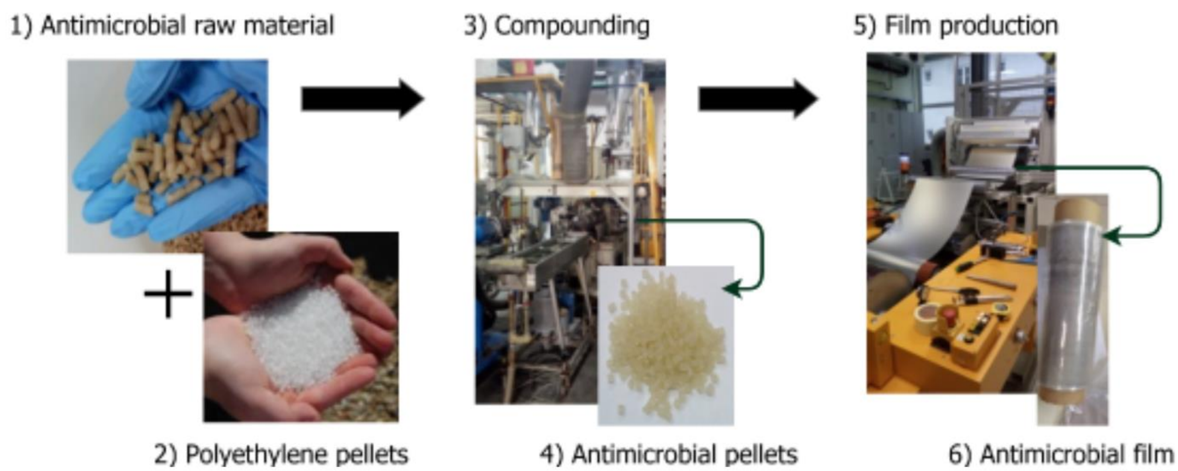


*Figure 8: Example Six Step Process of Producing an Antimicrobial Film Through Compounding with Polyethylene, Adapted from Van Dam, 2019*

This valorization of the shells and powder would not only find a use for the argan waste, but also cut down on food waste overall by preserving the encapsulated items for a longer period of time than traditional packaging. This packaging could also be directly applicable to food and agricultural products on the kibbutz. For example, this plastic can be utilized in shipping the processed argan oil produced by the kibbutz, which our sponsor mentioned as a potentially exciting option for this material. While machinery would be required for the compounding and film production processes, this is something the kibbutz has the space for and could be utilized in other forms of composite production. The compounding process requires machines including the crusher, feeder, and cutting mill, totaling in price to anywhere between $25,000-$40,000. As for the film production process, only a film making machine would be necessary and costs approximately $15,000 on average. These machines could additionally expand the composite manufacturing market overall for Israel.

## 4.3 Unmarketable

### 4.3.1 Liquid Biofuels

Liquid biofuels derived from biomass have been widely used for biodiesel, bioethanol, biogas, and bio-oil production through thermochemical and biochemical processes. While this is a promising field, the processes needed to create these biofuels would require a great deal of machinery, resources, and expertise to be successful. A biodiesel processor would need to be purchased, with costs ranging from $7,400-$15,000, with the machines lasting anywhere in a range of a few years to 10 or more (Da Tech, 2021). Smaller scale systems may be cheaper, but often require more maintenance, manpower, and quicker replacement times (Renner & McKeown, 2010). While this cost is similar to the other waste solutions presented, several processors would need to be purchased in order for the method to become profitable. The production of biofuels also releases greenhouse gases into the atmosphere and requires large amounts of water, making it less of an environmentally friendly solution than other highlighted uses.

With an assumed yield of 85 gallons per ton of cellulosic biomass, along with the energy potential of ethanol biofuel being 33% less than traditional gasoline, the kibbutz would need a large scale system with frequent production in order to make a profit off of this industry (*US Department of Energy*, 2021). The kibbutz would need to do extensive testing and consult experts to introduce ANS as an ingredient in biofuels, adding to the overall cost. In addition, biodiesel is very expensive to make, costing as much as $6.30 per gallon (Illukpitiya & de Koff, 2014). The pricing for this product also varies significantly each month, resulting in a very inconsistent market. The logistics behind selling biodiesel are very involved, delaying any potential implementation drastically and adding to the overall cost. When taking into account the expensive machinery and materials, extensive required energy and experimentation, negative environmental impacts, and variable marketability, we did not consider biofuels to be a reasonable waste solution for the kibbutz.

### 4.3.2 Large Scale Water Treatment

Another method for the valorization of ANS is large scale water treatment. In a study concerning the creation of eco-friendly biocomposites used in industrial wastewater filtering, ANS was combined with polyaniline through chemical oxidative polymerization to form a composite used in tandem with a filter. The results of this study showed that the polyaniline/ANS composite filtered aromatic acids, such as hemimellitic (Hemi), trimellitic (Tri), and pyromellitic (Pyro) acids, from the wastewater more efficiently than a composite without ANS (Laabd, 2017). This shows potential for use in large industrial cities, where wastewater is damaging the ecosystems, as part of the final steps of disinfection in the wastewater treatment process. While this is a promising idea, unless wastewater regulations require the removal of these specific acids, it is unlikely that companies will spend the extra money to filter them out. In addition, if the situation presents itself where these acids do need to be filtered out, companies most likely already have procedures for this and would be unwilling to implement this new composite unless it is significantly better. Although it would allow companies to advertise as more environmentally friendly, this would not be a large enough benefit to outweigh the investment. This results in a very small market for this use and no real benefits in comparison to similar acid removal methods already in place.

## 4.4 Recommendations

We have created a set of recommendations for the kibbutz to consider as they look to valorize argan nut waste. Based on the criteria outlined in our methods section, we created a qualitative comparison table (see Table 3) to directly compare the potential solutions with each other. This table uses a number range from 1-5 to compare the following topics necessary for each potential waste solution discussed above: equipment required, recurrent materials necessary, environmental impact, marketability, and further knowledge required. For each qualitative category, a 5 represents that the solution performs well in that category, whereas a 1 means that the solution is not ideal for that category.

*Table 3: Comparative Analysis of Each Potential Waste Solution*

| Category | Key | Kindling Blocks | Activated Charcoal | Active Packaging | Biocomposites/ Plastics | Bio-Fuels | Large-Scale Water Treatment |
|---|---|---|---|---|---|---|---|
| Equipment Required | 1: A lot<br>5: None | 4 | 3 | 3 | 2 | 1 | 2 |
| Recurrent Materials Necessary | 1: A lot<br>5: None | 5 | 3 | 4 | 2 | 1 | 1 |
| Environmental Impact | 1: High impact<br>5: No impact | 5 | 5 | 4 | 3 | 3 | 2 |
| Marketability | 1: No potential market<br>5: Large potential market | 4 | 5 | 3 | 2 | 1 | 2 |
| Further Knowledge Required | 1: A lot<br>5: None | 4 | 4 | 3 | 2 | 1 | 1 |
| Average Feasibility Score | | 4.4 | 4 | 3.4 | 2.2 | 1.4 | 1.6 |

**We recommend that the kibbutz begins producing kindling blocks in the short term and moves to activated charcoal production in the long term.**

Through our research and the direct comparison in Table 3, we recommend that the kibbutz looks at the implementation of kindling blocks as soon as machines can be acquired and begins to move towards the production of activated charcoal in the next 5-10 years. The kindling blocks require only two machines for production: a universal cutting mill and a hydraulic press (or other pressing device), in addition to the packaging methods. If the kibbutz chooses not to use a binder, which we recommend, there are no materials necessary other than the ANS. They can be sold locally, which removes the immediate difficulty of setting up an international distribution system. If the kibbutz chooses to continue producing fuel logs as the volume of material increases, they may choose to expand internationally.

In the long term, we recommend that the kibbutz invests in the production of activated charcoal as it requires the second most straightforward production process, behind the kindling blocks, in addition to the greatest potential for marketability. We also recommend that in this process, out of the two carbonization methods, the kibbutz utilizes the pyrolysis reactor over the steel drum set up. The pyrolysis reactor has already been tested with argan nuts so there will need to be less testing than the steel drums before implementation, and it also creates the most controlled environment during pyrolysis, resulting in a more consistent product. Out of the two activation methods compared, we recommend that the kibbutz utilizes physical over chemical activation. While the physical activation creates a product with slightly less adsorption capacity, the same pyrolysis reactor can be used as in the carbonization step, no chemicals need to be purchased, and the end product will still be suitable for water filtration, for air purification, and as an ingredient in cosmetics.

Like with the kindling blocks, a universal cutting mill is needed, along with a tube furnace. This is supplemented with the continual purchase of the nitrogen used in both pyrolysis and physical activation. As the kibbutz implements activated charcoal, they will be able to use the same universal cutting mill as used for kindling block production, which then only requires the purchasing of one new machine. There will be a transitional period where the kibbutz will need to install machinery, test products, and have them approved for market, delaying the implementation of this idea and making it more feasible for the long term. Prior to distribution and sale, the kibbutz will need to have the products tested for chemical composition to ensure that they are safe for human use. During this time, they will continue to earn a profit from the kindling block production, resulting in no buildup of waste or halting of income. The marketability for the activated charcoal is also the greatest out of all the potential waste solutions, as the three proposed uses provide market diversity in a field that is expected to experience continuous growth.

# 5. Conclusion

As Kibbutz Ketura begins to scale up their argan tree farming operation, argan nut waste is accumulating without any profitable uses. To reduce the amount of waste and prevent environmental pollution, it is vital that the kibbutz determines profitable uses for these unutilized materials. The project identified ways to valorize argan nut waste. We researched kindling blocks, activated charcoal, biocomposites/plastics, active packaging, liquid biofuels, and large scale water treatment. We divided these waste solutions into implementation categories of easy to implement; requires further research to implement; and unmarketable. Our implementation analyses outlined the production processes, equipment and materials needed, environmental impact, potential marketability, and further knowledge required. This creates a solid foundation for Kibbutz Ketura to work with as they move forward into the implementation of one, or potentially multiple, of these ideas.

Based on our research, we recommended that the kibbutz begins by implementing kindling blocks and strives to implement activated charcoal in the next 5-10 years after regulatory testing and authorization. These recommendations provide valorizations of the waste from the argan nuts while providing marketable products, creating the opportunity for argan trees to become a beneficial crop at Kibbutz Ketura and beyond. We hope that these findings and recommendations can assist other similar agricultural operations with utilizing their waste outputs and ultimately cutting down on the negative environmental impacts of argan waste.

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# Appendix A: Formatted Chemical Report

| | Kernels batch 1 | | Kernels batch 2 | | Fresh fruit | | Dried fruit | | Nut shells | | Outer peel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fresh | Dry | Fresh | Dry | Fresh | Dry | Fresh | Dry | Fresh | Dry | Fresh | Dry |
| Dry matter (%) | 97.24 | | 97.65 | | 41.81 | | 97.75 | | 94.61 | | 93.38 | |
| Ash (%) | 2.19 | 2.25 | 1.94 | 1.99 | 1.30 | 3.10 | 3.27 | 3.35 | .44 | .47 | 6.28 | 6.72 |
| Protein (%) | 18.66 | 19.19 | 20.85 | 21.35 | 1.58 | 3.79 | 5.14 | 5.26 | 1.09 | 1.15 | 7.09 | 7.59 |
| Vapor (%) | 50.16 | 51.58 | 56.96 | 58.33 | 20.17 | 48.25 | 59.79 | 61.17 | 89.28 | 94.37 | 12.53 | 13.42 |
| ADF (%) | 17.52 | 18.02 | 32.48 | 33.26 | 14.52 | 34.72 | 40.83 | 41.77 | 60.01 | 63.43 | 8.40 | 9.00 |
| Lignin (%) ADL | 9.10 | 9.36 | 11.28 | 11.55 | 6.42 | 15.36 | 17.82 | 18.23 | 28.18 | 29.79 | 2.74 | 2.93 |
| Fat (%) | 36.48 | 37.52 | 30.31 | 31.04 | 2.60 | 6.21 | 6.79 | 6.95 | .31 | .33 | 2.47 | 2.65 |
| Calcium (%) | .44 | .45 | .32 | .33 | .20 | .48 | .51 | .52 | .20 | .21 | .41 | .44 |
| Phosphorus (%) | .37 | .38 | .28 | .29 | .13 | .31 | .28 | .29 | .18 | .19 | .20 | .21 |
| NEL Assessment (MKL/Kg) | 2.67 | 2.75 | 2.18 | 2.23 | .65 | 1.56 | 1.36 | 1.39 | .73 | .77 | 1.88 | 2.01 |
| Cellulose (%) | 32.63 | 33.56 | 24.48 | 25.07 | 16.16 | 38.65 | 18.96 | 19.40 | 29.27 | 30.94 | 4.14 | 4.42 |