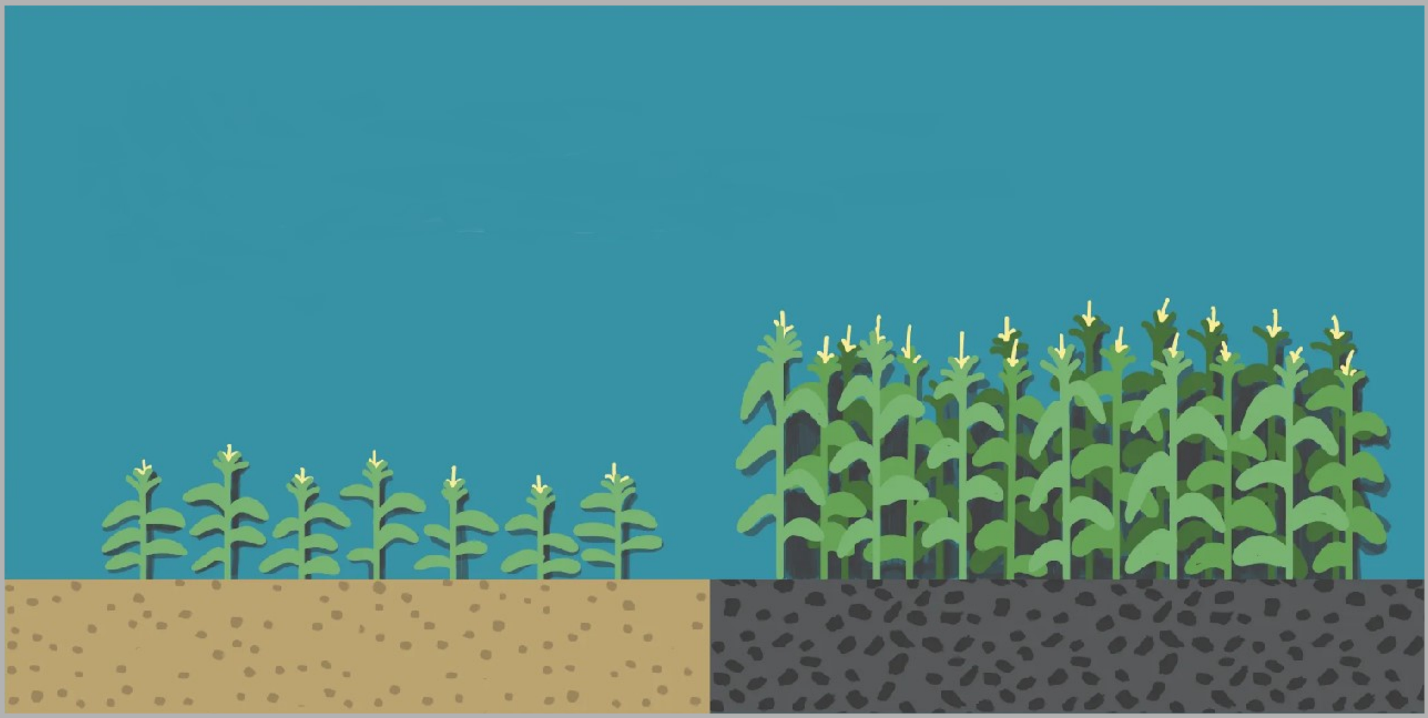
Exploring Biochar Options for the Hunter Valley Region



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Abstract

As the effects of climate change and greenhouse gases become more severe, steps must be taken to mitigate and reverse these effects. Biochar is a material made from processing organic waste that can prevent greenhouse gases from entering the atmosphere. The goal of this project was to assist Beyond Zero Emissions in Melbourne, Victoria and local researcher Aimee Mehan to develop potential strategies for establishing biochar production facilities in the Hunter Valley Region of Australia. The project team investigated case studies and other publications on the requirements for biochar production and the potential benefits of biochar, as well as the ability for those needs to be met in the Hunter Valley. We then conducted interviews with local stakeholders and a survey of Hunter residents. Finally, we completed a life cycle assessment to analyze the environmental impact of the biochar production process. We discovered community support for biochar among those who responded to our survey, as well as from the local experts and government officials we interviewed. We also found promise in the positive environmental impacts of biochar through our life cycle assessment. Overall, our findings suggest that there is support and potential for a biochar project in the Hunter Valley Region.

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Introduction

Greenhouse gas emissions have been on the rise since the 1900s due to the extensive global use of fossil fuels as an energy source. The Environmental Protection Agency asserts that since the 1970s global carbon dioxide emissions have increased by 90%, and have severely contributed to climate change (2020). Climate change has created countless negative effects around the globe: rising temperatures and sea levels, ocean acidification, and an increase in extreme events such as forest fires. According to NASA,

“The planet's average surface temperature has risen about 2.05 degrees Fahrenheit (1.14 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere” (2020).

Australia has contributed to global emissions by being the global leader in coal exports worldwide as well as relying heavily on fossil fuels for its own energy production. Australia has also been victim to climate change, with their coral reefs suffering from ocean acidification and rising temperatures causing more prolonged drought seasons that lead to more intense bush fires (The Climate Reality Project, 2019). These extended droughts cause even greater strains on Australia’s already limited water supply, creating problems for water-reliant industries such as coal mining and coal-based electricity production. All these issues have led to the emergence of new practices to relieve the strain on the environment.

Bio-friendly practices have emerged as a potential solution for ensuring the environmental resilience of areas affected by the above problems. The Hunter Valley Region of New South Wales has relied heavily on coal for their power needs, which releases many harmful chemicals into the air. In an attempt to sequester carbon and respond to rising levels of greenhouse gases, several organizations have explored the potential of biochar, a charcoal like substance that can be made from the controlled burning of organic materials from forest or even backyard waste. Biochar not only sequesters carbon but also reduces waste, and when used to enrich soil, improves soil quality and increases water retention.

In order to make biochar production feasible, the Hunter must establish the proper systems for it to work, which includes collecting and preprocessing the feedstock, processing the biomass in a facility, and shipping and distributing of the final product for use in relevant areas in the Hunter. Investigating the community support, availability of resources, and assessing the environmental benefits and drawbacks for a proper biochar system will serve as an important tool for stakeholders in the Hunter to begin the process of implementing biochar use throughout the region.

Developing a system to utilize biochar as a fertilizer in this region of Australia is a relatively new venture. There is very little groundwork laid for developing a biochar production facility in this area, which is what makes our project so important. New South Wales has a well-established forestry sector (over two million hectares of forestry across eight regional areas) managed by a number of timber companies (Feedstock Logistics, 2020). These timber companies produce a large amount of wood waste that comes from reducing logs down to usable timber. We set out to examine this and other potential feedstocks for biochar production in the area along with others. An abundant amount of green waste is being heavily underutilized and every year is thrown into landfills.

Our sponsors, local researcher Aimee Mehan and solutions think tank Beyond Zero Emissions (BZE) had already begun the collaborative exploration of a biohub before we began the project. They asked us to continue reaching out to local businesses, industry leaders, researchers, government agencies, and others invested in the well-being of the Hunter Valley, as their goal was to identify existing research, interests, activities, and projects related to bioenergy and to unify stakeholders in the implementation of Hunter wide biochar plan (BZE, Diversification and Repower Plan, 2020). Our team goal in this project was to develop a system for BZE and Aimee Mehan that would outline potential opportunities to sequester Greenhouse Gases.

We set several objectives and used a variety of methods to achieve them, which appear in Figure 1. Our first objective was to build our knowledge of the Hunter Valley. We first set out to understand the social, environmental, and economic workings of the region. Our second objective was to research biochar production systems and what materials can be used to produce biochar.

Our third objective was to identify local knowledge, resources, and interest relevant to biochar production at a small, medium, and large scale. We did so by interviewing local experts, as well as surveying residents to gauge their interest in participating in different types of biochar systems. Our fourth and final objective was to assess the feasibility of implementing a biohub at each scale, to see the environmental and monetary costs.

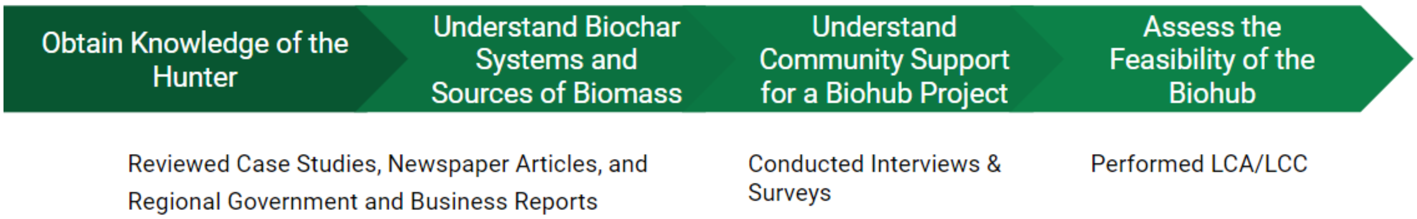


Figure 1: Objectives and Methodology

Chapter 1: The Hunter Valley and the Potential of Biochar

The Hunter Valley Region is one of the largest river valleys on the New South Wales coast. The region is famous for hectares upon hectares of vineyards, which support over 150 wineries (Explore The Hunter, 2019). The location of the Hunter is highlighted in orange in Figure 2. The Hunter has a large tourism industry , due to its many natural attractions like Wallarah National Park, as well as many cultural events and festivals. The Hunter is actually the sixth most popular place to visit in Australia (Explore The Hunter, 2019). Lake Macquarie is a popular natural attraction, the largest coastal saltwater lake in Australia, it covers an area of roughly 110 square kilometers (Explore The Hunter, 2019). Port Stephens is another popular place to visit, sporting the largest sand dunes in the Southern Hemisphere.

Newcastle is the largest city in the Hunter and is located on the coast as shown in Figure 2. 155,000 people live in the city, and 5,500 (3.5%) of those people are Aboriginal and/or Torres Strait Islander people: another 84.5% of the population identify as having Australian, English, Irish, Scottish, and/or German ancestry (2016 census QuickStats, 2016). The rest of the Hunter (excluding Newcastle) supports a population of 263,000. Of this 263,000, 15,000 are Aboriginal and/or Torres Strait Islander people, composing 5.7% of the population. It is important for us to understand the makeup of the population in order to address potential cultural issues with our project, as well as to simply have a deeper understanding of this place. The economy of the Hunter is very diverse, with sectors ranging from aerospace, coal mining, and advanced manufacturing to tourism, winemaking, and the food industry (Hunter, 2020). The combined output of these industries is over 34.7 billion Australian dollars, with coal mining making up around 38% of that total. Companies such as Boeing, Raytheon, Lockheed Martin, and BAE systems all have locations near the RAAF Base Williamtown (Hunter, 2020) which is shown in Figure 2. In addition to these industrial powerhouses, the Hunter also is home to many research institutions such as the CSIRO Energy Centre, the Port Stephens Fisheries Institute, the Newcastle Institute for Energy and Resources and the Hunter Medical Research Institute. Another institution of note is the University of Newcastle which contributes significantly to the quality and diversification of the workforce in the Hunter. The university also does a wide variety of world class research in various topics that range from industrial research for companies in the Hunter to international consortiums with other universities (Newcastle University, 2020), further benefiting the innovative nature of the Hunter economy.

Figure 2: New South Wales (Regional NSW, 2020)

The Hunter is also a very well-connected region of Australia. Located in the southern area of the Hunter, the Port of Newcastle is the world's largest black coal exporter and the 24th largest port in the world by trade volume (Fletcher, 2020). There are many railways and major shipping roads in the region, as shown in Figure 3. Highway 1 runs up the east coast of Australia, connecting Brisbane and Melbourne through Sydney, and thus the Hunter Valley as well. The railways follow a similar path to the major roadways, giving the Hunter several strong options for import and export of trade goods. The Hunter mainly exports coal, copper, and aluminum due to the many mining companies in the area, whereas the imports are generally manufactured goods from China and Japan (NSW Treasury, 2017).

Figure 3: Transportation Infrastructure in The Hunter Valley Region (Regional NSW, 2020)

Opportunities for the Hunter to Adopt Biofriendly Practices

The energy systems in Australia are currently going through their biggest transformation since the 1950's (Australian Government, 2020). One major reason is increased pressures from the crises caused by climate change. Climate change has created countless negative effects around the globe, "The planet's average surface temperature has risen about 2.05 degrees Fahrenheit (1.14 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere" (2020).

Emerging climate-related issues have proven to be a large inspiration for Australia to find ways to reduce carbon emissions. Even though it is still a relatively small part of Australia's energy production, the renewable energy market has grown in the past years. In the electricity generation sector, the main sources of production are wind (35%), solar (33%), and hydro (25%) (Clean Energy Council, 2020). However, alternative fuel sources aren't the only solutions to the problem. Biochar could prove to be a very effective way to sequester carbon from the atmosphere while also providing an effective way to dispose of a variety of types of biowaste. This biowaste can exist in many forms and can be processed to produce many types of biomaterial products.

Another way that climate change can be addressed is on a small scale, in homes and communities. Almost every home has a significant carbon footprint, whether that comes from electricity usage, emissions from cars, waste disposal, or other sources, but very few homes have measures to reduce their carbon emissions. Permaculture is one such way that households can reduce their carbon emissions by implementing the use of biochar.

Permanent agriculture, more commonly referred to as permaculture, is a system of guidelines and philosophies for designing and implementing sustainable gardens, farms, and even larger community green spaces. The modern interpretation of permaculture, developed by David Holmgren and Bill Mollison, "Presents an approach to designing environments which have the diversity, stability, and resilience of natural ecosystems with the productivity of naturally improved plant varieties and technologies from many cultures and countries" (The Food Forest, 2016).

There are five main principles of permaculture (The Food Forest, 2016):

1. Reading the landscape
2. Placement of elements in the design
3. Energy
4. Using biological resources
5. Multifunctional elements

Reading the landscape involves observing where the land is naturally wet or dry, where shade naturally occurs, soil quality, and other naturally occurring aspects of the landscape. Placement of elements is important because it's all about ensuring that as many aspects of each element are optimally used. For example, a fruit tree can bear fruit, but it can also provide shade to plants that need it and can help prevent soil erosion. Energy is meant to remind those who practice permaculture to minimise the amount of energy put into the system. This could mean placing a water collector uphill of where plants need to be watered so that the water can be gravity fed. Using biological resources means that instead of using chemicals or weeding by hand, one could plant a low-growing plant to crowd out unwanted weeds, or it could mean keeping a few chickens to reduce the bug population. Multifunctional elements are design considerations that can perform multiple functions, such as keeping sheep that graze the land to reduce weeds and grass while also being a way to dispose of food waste, a source of wool, and also a source of fertilizer for a garden or field of plants. One long-running example of permaculture is the Food Forest in Australia. "The Food Forest is a permaculture farm and learning centre that demonstrates how an ordinary family, with a typical Australian income can grow its own food and create a productive and diverse landscape" (About The Food Forest » The Food Forest, 2020). They also teach classes on permaculture and offer a consultancy service to help people properly utilize permaculture in their homes. The Food Forest supports over 150 plant and timber varieties, as well as a number of animals, over a land area of over 15 hectares, or 37 acres (Permaculture Research Institute, 2016). The Food Forest is in a relatively dry region, somewhat comparable to California.

They deal with this with very efficient irrigation and mulching practices, meaning that while commercial fruit farms use around 10-11 megaliters of water per hectare per year, the Food Forest uses the same amount for seven hectares (Permaculture Research Institute, 2016). They also process all food waste through their animals, and even receive additional compost and green waste from Adelaide. Although our purpose was not to install sustainable farms or gardens, we believed that permaculture was an important part of educating residents of the Hunter to be more mindful of their impact on the environment. It also broadened our thinking as we put together our recommendations for this project.

Feedstocks for Biochar

Using organic waste as a source for bioenergy is what makes the bioenergy production process so effective. Biomass feedstock is a term that refers to a variety of organic materials that can be processed into a variety of products, also referred to as biomaterials. Biomass can be found in many different areas like residue from timber companies, farms, and even the home or garden. The Hunter Valley is home to these abundant types of biomass.

Forestry Residue

New South Wales (NSW) is made up of more than 15% of Australia's forests, or 20 million hectares (A.U. Department of Agriculture, Water, and the Environment, 2020). Forestry residue and leftover farm biomass are abundant in New South Wales. Forestry residue is made up of branches, leaves, stumps, and thinner trees that cannot be used for timber. Even though these are very abundant biomass sources, "forestry biomass is bulky, heterogeneous, and prone to degradation if it is stored for long periods of time" (Bioenergy Alliance Network of the Rockies, 2020), this makes the price and the logistics of working with forestry residues more difficult. In a recent report seen in Table 1 by ABARES (Australian Bureau of Agriculture and Resource Economics and Sciences) about future opportunities for using forests and sawmill residues, they stated that there was over 3 million green tons of forest residue that was harvested from 2011-2015. Out of all of the residue harvested, most of it is made up of hardwoods and softwoods. However, out of the hardwoods and softwoods that are harvested, less than 40% of it can be used for timber production (ABARES, 2018). The only portion of the tree that can be used is the sawdust residue, as well as bark and slices leftover from turning a log into a piece of lumber. This is gained from cutting off the round edges to make the square lumber that will be used for whatever purpose. The unused biomass at these timber factories would be perfect for biochar production.

Table 1: Estimated Harvest Residue Availability Per state

State	Hardwood native (t)	Hardwood plantation (t)	Softwood (t)	Total (t)
Victoria	na	917,557	1,054,818	**1,972,375**
Tasmania	672,000	297,000	110,000	**1,079,000**
Queensland	766,414	na	308,344	**1,074,758**
New South Wales	1,948,486	163,044	979,520	**3,091,050**
Total	**3,386,900**	**1,377,601**	**2,452,682**	**7,217,183**

na Not available.
Note: All estimates are in green tonnes.
Source: ARENA 2017

Timber Waste

Catherine Pepper, who is manager of Environment and Sustainability at Maitland City Council, informed us that New South Wales as a whole will see a large increase in demand for timber products from the large population boom they will see in the next 15-20 years. With the demand of 600,000 more homes to be built and timber being the primary source of the material to make this possible, there will be a large increase of the supply of timber products (DPI, 2016). This increased supply of timber waste will come from all of the timber companies' waste after milling down a log to produce viable timber for construction. Figure 4 shows the breakdown of all of the products and waste created after milling a tree. The products that will be most valuable for biochar production will be the sawdust, wood chips, croakers, bark, as well as the branches. These are the leftover materials that timber companies normally shred down and use for agriculture mulch but, using this material as a potential source of biomass feedstock will not only help reduce waste but it will also aid in sequestering carbon from the atmosphere.

Figure 4: Timber Waste (Komeleva, 2018)

Agricultural Biomass

Agricultural biomass is “derived from biological organisms such as grains and crops with high sugar content, straw, plants, and perennial grassess” (Skou 2019). In Figure 5, this form of biomass is abundant in NSW. When we considered looking to farmers as a reliable source of biomass it was not to displace crops needed for food or for feed. As farmers start to look towards the future after years of drought,biochar might give them hope. Farmers could not only gain from the increased income from the sale of the biomass and from getting carbon credits from helping reduce their overall carbon footprint, but they would also be able to fight against drought and decreasing soil quality from the benefits of using biochar. They will actually be improving their soil by planting the correct organisms to promote these environmental benefits (Bernasconi, 2020).

Figure 5: Agricultural Waste Crops (Freudenberger, 2020)

Green Waste

As we conducted our research we realized that a few councils in the Hunter utilize a collection system commonly referred to as the “green bin”. As seen in Figure 6, green waste is made up of organic, compostable waste that can be found at the home. The most common sources of this organic waste are garden waste, yard clippings, flowers, and even loose branches. These are materials that could be feedstock for producing biochar but this is not the only source. From our interviews we gained knowledge that the Hunter has a large variety of timber companies that produce copious timber waste that is widely underutilized.

Figure 6: Green waste

Regenerative Forestry

Being able to harvest all of this residue from homes and timber companies is very beneficial, but unless it is done sustainably, the health of the forest will decline. Proper forest management and sustainable harvesting is the only way to protect a healthy thriving forest while having it provide renewable raw materials and biomass. Forest management can be broken up into two primary subcategories: forest removal and forest recovery. Sustainable forest removal is done by partial cuts of the forest to thin out the "losing" trees, as well as some healthy ones too. This allows more room for previous trees to thrive and small new growth to occur as well as providing some timber and biomass to be gained from some of the healthy trees. Once these resources are harvested new trees must be planted, but it is vital that the correct species be selected. One organization aiding in sustainable development is the Department of Primary Industries. Their focus is to aid businesses throughout New South Wales with whatever help is needed. Recently DPI aided the Tamworth Agricultural Institute by planting 6,000 trees and they will be harvesting them in three years' time for a sustainability analysis. This research will measure the effect these species have on the soil quality as well as the growth of these six native species: silver wattle, green, blue and Durikai mallee, sugar gum, and river red gum (Bernasconi, 2020). Proper forest management is important to ensure that soil quality does not decrease when new trees are planted and is also aided by the natural regeneration of the forest.

The forestry sector in New South Wales is a $2.4 billion dollar industry, but as the demand for wood products increase, the industry must expand to meet it. As shown in Figure 7, the population of NSW is increasing on average at a rate of 100,500 people per year with Sydney's population expected to increase to 5.86 million people (DPI, 2020). This is going to trigger an increase in demand for wood products for construction and without proper forest management and sustainable harvesting practices Australia's forests will suffer.

Over the last 25 years, the number of new tree plantations has dwindled from 120 every year to less than 5 per year. The Australian Bureau of Agriculture and Resource Economics and Sciences stated in the *New Growth for Australia's Forests*, "The area of commercial plantations did reduce by 44 thousand hectares or 2 percent between 2010-11 and 2014-15" (ABARES 2019). This is why the government has a goal of one billion new plantation trees made possible by creating a budget of 20 million dollars for the renewable timber and wood-fibre industry between 2018 and 2021. This funding plans on transforming farm forestry to a commercial enterprise for supplying timber and creating regional forestry hubs that expedite the transport and access to the market.

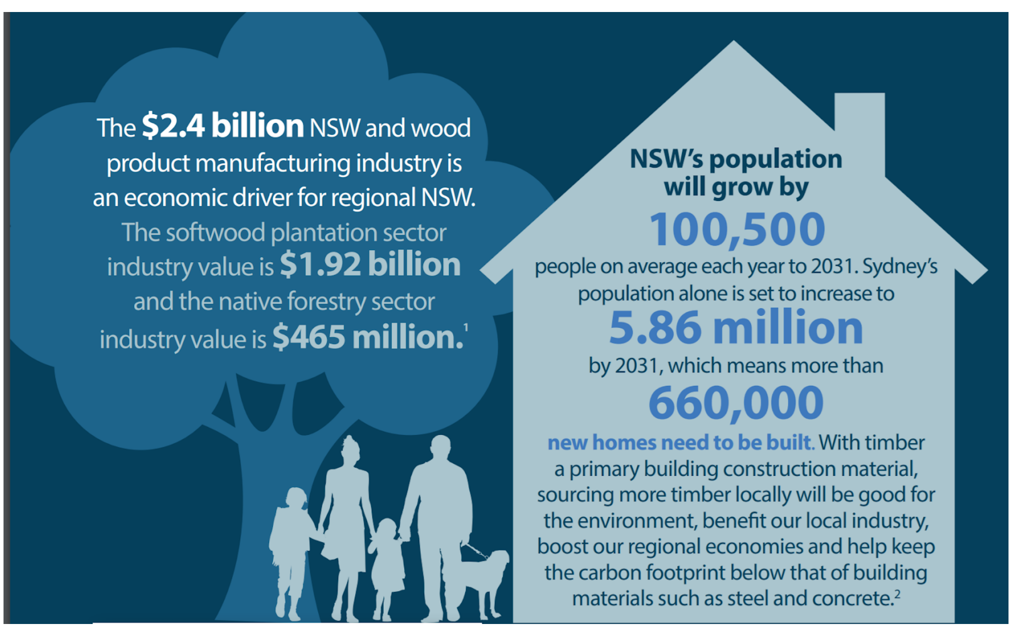


Figure 7: New South Wales Forestry Industry (DPI, 2016)

Feedstock Life Cycle

In biochar production, one must consider the feedstock life cycle. As seen in Figure 8, the feedstock life cycle starts by cultivating the land with good harvesting and forest management, well located storage facilities to allow for easy transport, as well as modern preprocessing methods. The most important part of harvesting and collecting the biomass for feedstocks is collection timing and strategy. For example, when a field is being harvested most of the plant is being harvested for food or for animal feed, but whatever is not being used needs to be separated simultaneously. This will ensure consistency in the biomass collection process. In our interview with David Holmgren we learned that keeping the quality of the biomass consistent is very important when producing biochar. Having an inconsistent quality of biomass will alter the amount of biochar produced as well as the environmental effects of this biochar.

For most of these plant-based organisms, this preparation stage before converting biomass into suitable feedstocks is simple. This step is called preprocessing. The biomass has to be collected, chopped, and ground into tiny pieces. Then they are mixed in with water and special enzymes which convert the cellulose in the organisms to sugars. The next step of converting these pebble-like pieces of feedstock is where it gets difficult. The particulates are then placed into a large vat and cellulosic enzymes are added that digest the cellulose into sugars Smyth, n.d.). Agricultural residues like switchgrass have many second hand benefits that can be incorporated into using it as a biofuel such as reducing soil erosion and water consumption from its deep roots, improving water quality by preventing water runoff carrying pesticides into streams and rivers, sequestering carbon, and overall increasing soil quality. Once the biomass has been preprocessed the production of the biomaterials is possible.

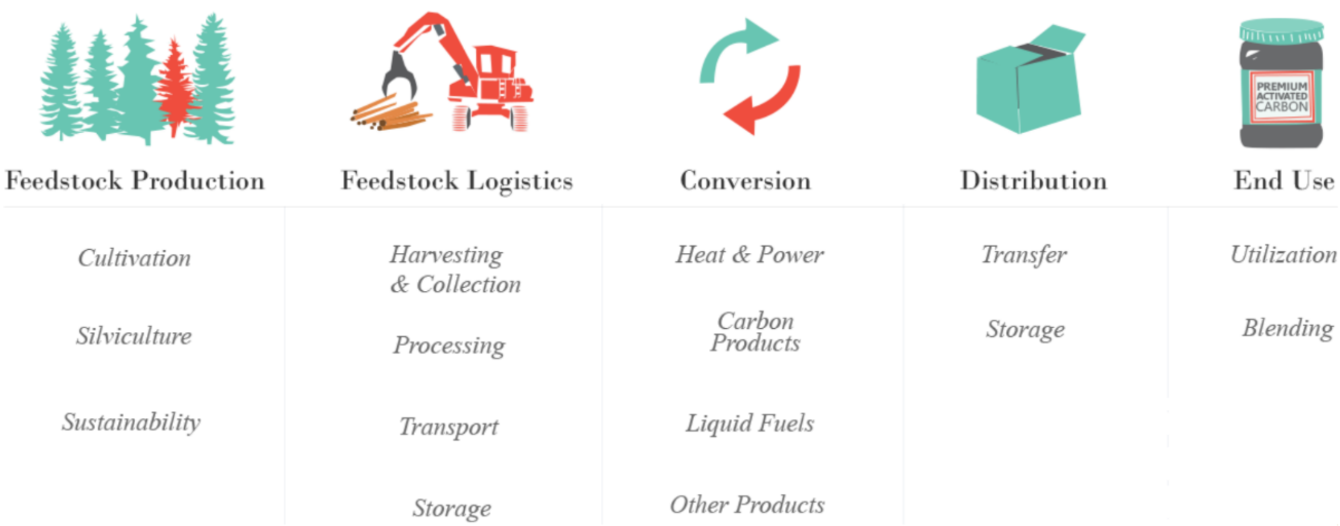


Figure 8: Feedstock life Cycle (BANR, 2020)

Biochar's Composition and Benefits

Biochar is a form of charcoal that is primarily used as an additive for agricultural purposes as shown in Figure 9. An article written by Regeneration International, ("What is Biochar", 2018), discussed benefits biochar can have when used in agriculture. One advantage specifically in the case of our group's project is that biochar is most optimally made from "feedstocks with high lignin content" (Regeneration International, 2018), in other words, wood feedstocks. Biochar has a multitude of uses in agriculture and power production as a regenerative energy enabler. This report lists all the benefits that biochar can have when used in plant farming such as: better soil fertility, less soil erosion, increased pH level leading to better soil quality, to name a few. The full list can be seen in Figure 9 as well.

Figure 9: Benefits of Biochar as a Soil Amendment

Biochar can not only be produced from feedstocks but be used to aid in the growth of additional feedstocks, which can lead to more biochar production. Also, it has the added benefit of lowering total plant greenhouse gas emissions. As farmers make the switch to biochar as their primary fertilizer they will no longer be using nitrogen emitting fertilizers. The switch to biochar reduces total greenhouse gas emissions by 28-40% (Medium, 2020). Thus, both biomaterial products, biofuel and biochar, have benefits and both come from the production process.

Biochar Production

The biochar production process, as seen in Figure 10, is known as pyrolysis, which works by burning biomass feedstocks in a low oxygen environment oven that encourages chemical decomposition (Biofuel Journal, 2018). After the pyrolysis process is finished you are left with a slurry. This slurry is then passed through a cyclone process that separates the biochar from the slurry. The slurry is then sent to the quencher which cools the slurry and strains out any remaining large particulates that are sent back to the pretreatment phase for recycling. The liquid that is left is known as bio-oil and is stored until it is refined into ethanol. During the production of biochar syngas, or synthetic gas results as a byproduct.

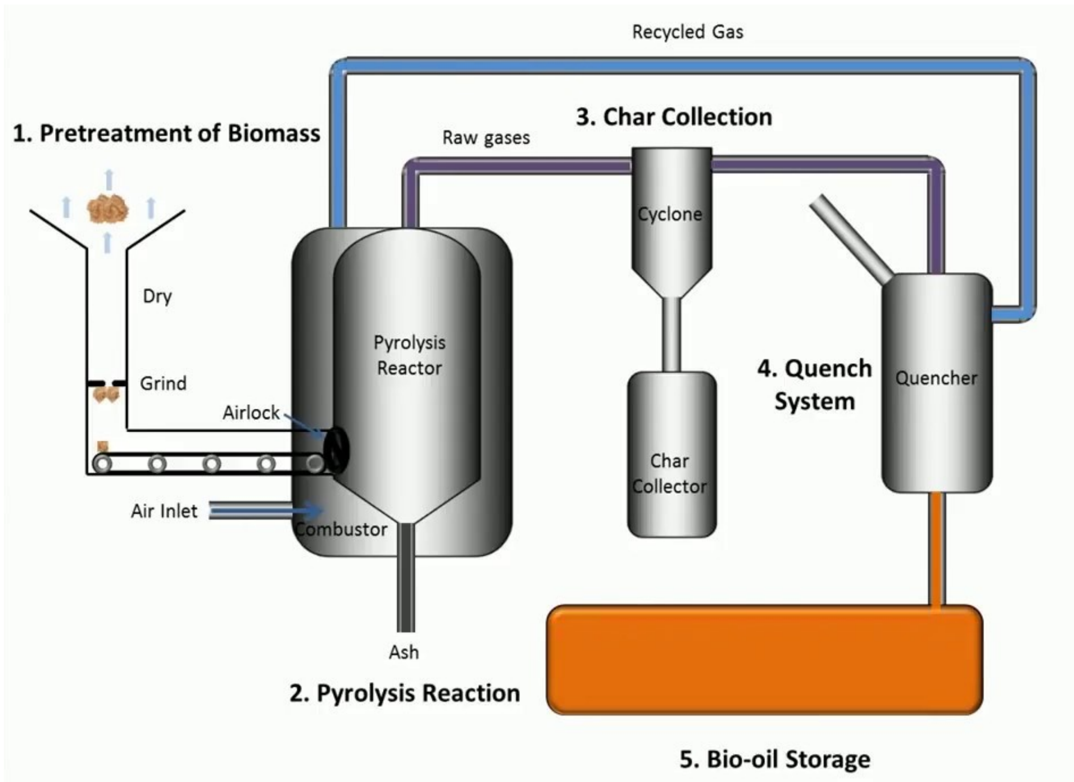


Figure 10: Biomaterial Production Process (Biofuel Journal, 2018)

Syngas is “a mix of molecules containing hydrogen, methane, carbon monoxide, carbon dioxide, water vapor, as well as some hydrocarbons and condensable compounds.” (Biogreen, 2020). This syngas byproduct has many uses, but we focused on its use in heat and power generation. Biochar production by pyrolysis is a relatively simple process, and can be done at a variety of different scales. We examined three in this project, which are explained in more in the following chapter. In our project, we considered three scales: small, medium and large. The small scale would be a system that each household could have, the medium would be operated at a council level, and the large scale would be a system drawing waste from the whole Hunter.

Chapter 2: Community Support & Stakeholder Interest

To better understand the practices and views of our stakeholders in the Hunter we established contact with local residents, business owners, and government officials. We chose to do so as we wanted to understand the interest, resources, and feasibility of biochar production at different scales.

Interview Data and Results

We began by developing a list of organizations that we believed could have useful knowledge about biofriendly practices, the local economy, related industries, and the political and social climate. When we met with Dominique from BZE and Aimee Mehan we discussed this list and our interests, and we came up with a list of people to connect with, which is shown in Table 2.

Table 2: Interviews Conducted

Interviewee	Subjects Covered
John Shiel	Energy Sector
Anabel Kater & Su Morley	Forestry Management & Community Engagement
Tim Askew	Sustainable System Economics
David Holmgren	Permaculture
Catherine Pepper & Elfi Blackburn	Green Waste Collection & Management
Jonathan Wood	Project Feasibility
Michael Askew	Bioeconomy
Joe Herbertson	Biochar Production

Our team primarily gathered information through zoom interviews. Those interviews had different topics based on the interviewee in order to find useful information in different sectors, i.e. government, business sectors, non-profits, and research institutions. Prior to conducting the interviews, each participant was given a preamble, (Figure 11), describing the purpose of the project and who we are, as well as a request for their consent to participate. We recorded these interviews, with permission, for later review.

> Hello,
>
> We are four mechanical engineering students attending Worcester Polytechnic Institute in Worcester, Massachusetts, United States, and we are conducting a study with Beyond Zero Emissions and local researcher Aimee Mehan in Australia.
>
> The purpose of this study is to identify ways the people of the Hunter might work across sectors and coordinate systems to repurpose waste and build the local economy. We will be conducting interviews to get your thoughts on how to build the economy through bioenergy, as well as learn the different ways that everyone can contribute. Results from this study will be published on our University website (WPI) and our recommendations will be presented to local groups who are interested in implementing a biochar production system in the Hunter region. This biochar system will benefit the local community in a variety of ways by making new connections between industries to help them work together for mutual economic and environmental gains such as creating new jobs, allowing businesses to sell materials that were previously categorized as waste, and reducing fossil fuel usage and greenhouse gas emissions.
>
> If you choose to get involved in this interview, you are free to end it at any time, and you may choose not to answer any of the questions. Your name need not be identifiable in the report if you don't wish it; if you request it, we will instead refer to you by a pseudonym (Farmer 1, Stakeholder 1, Community Member 1, etc) If you choose to sign your name below, you will acknowledge your willingness to participate in our interview, which will take roughly 45 minutes to an hour. If a digital signature isn’t possible, we will ask for verbal consent at the beginning of the interview. We would like to record this interview so we can look back as we construct our report, but it is up to you whether we do so or not. The recording would only be available to our team. If you have any questions about the study or wish to

Figure 11: Interview Preamble

We sought information on the current biofriendly practices used as well as where there might be potential to establish these biofriendly practices to support our biochar production systems. Our types of stakeholders and topics of interest can be seen in Table 3. We used sampling by convenience, contacting those recommended by BZE. We also used snowball sampling, asking interviewees if there were any people, businesses, or organizations that came to mind that may have knowledge or engaged in biofriendly practices. This allowed us to interview subjects who were more interested in our project and would provide us with more insight and build a deeper knowledge in our areas of interest.

Table 3: Stakeholders and Topics of Interest

Stakeholder	**Topics**
Local Government Organizations	Waste management policies across the Hunter
Hunter Joint Organization	Potential for working across councils, circular economy, community engagement strategies, environmental collection data
Residential Landowners	Interest in composting/recycling, garden maintenance and current waste disposal practices
Forestry Businesses	Current harvesting practices, waste management
Australian Government	Current policies, incentives, climate change
Resilient & Sustainable Nature Practice Experts	Current practices, implementations
Biochar Production Businesses	Comparison of scales, economy of scale, difficulties with procuring feedstocks, economic viability, environmental benefits of biochar

Benefits of Biochar

Drawing from our interviews with experts we learned even more about biochar and the ways that carbon sequestration can be used. We learned from our interview with David Holmgren, the co-originator of permaculture, more about the life cycle of biochar. Trees and plants use photosynthesis to capture carbon from the air, which is then used to produce biochar. When the biochar is buried in the ground, carbon has effectively been removed from the atmosphere and then repurposed in the form of biochar to continually trap further carbon release from the soil. This drawdown of carbon would serve to slowly lower global carbon emissions. In addition to our interview findings on the carbon positive benefits of biochar, we also learned from Joe Herbertson, director of the Crucible Group, that biochar can serve as a home for microbes. These microbes are vital for plant life and proper soil nutrition. The implementation of biochar as a soil additive would serve as a place for these microorganisms to thrive. Joe Herbertson also spoke on the benefits that wood vinegar, a byproduct of the biochar production process, can have when used in soil. Wood vinegar is an acidic liquid that contains many nutrients that are key for the microorganisms in soil. When wood vinegar is used in tandem with biochar it creates the basis for excellent soil quality. Our discussions not only added to our knowledge of biochar, but also to the benefits that processing timber waste could have on the local areas.

We spoke with David Holmgren on the potential positive impacts that biochar production could have on the forestry sector. Producing biochar requires biomass, which comes in different forms. Using timber waste as a source of biomass could be beneficial, as this could potentially lower the disastrous effects of forest fires in Australia. The reason behind this, as Mr. Holmgren explained to us, is that these bits and pieces of wood that can't be sold or used provide a significant source of fuel for forest fires. If this woody waste were to be removed and used it could serve to lower the severity of forest fires in the region.

Timber and Forestry

During one of our interviews with Annabel Kater, she relayed to us that Australia has many regulations regarding what can and cannot be taken from the forest floors. Only logs that have previously fallen can be taken and used for other purposes such as for biomass feedstock. Timber waste, however, is not regulated by the government; it is up to each timber mill to decide what happens with their waste. Most timber mills chop up the leftover material from making timber and combine it with all of their shavings and sell it as mulch. This is a great avenue for them to take because it is a start to sustainable timber harvesting, but Joe Herbertson said these companies could go one step further. Timber companies could sell their waste for biochar production, which not only furthers their goal as an environmentally sustainable business, but also adds a lot of value to the wood chips they sell, incentivising them to sell to biochar production companies rather than for mulching. According to Mr. Herbertson, the prices of wood chips could be raised from the current price range of tens of dollars per ton to potentially hundreds of dollars per ton if the biochar and wood vinegar are properly captured and marketed. We also learned in an interview with David Holmgren that sourcing the biochar isn't the only problem you have to deal with. The quality of this biomass has a large effect on the output of the biochar as well. If you are able to source the material from better managed land plots the quality of the harvested timber is higher, which ultimately increases the quality of the biochar.

Agricultural Sources

During our discussion with Annabel Kater we were told that sourcing biomass from farms would be tricky, considering they already use everything they possibly can out of their harvests. Farmers usually compost their green waste or manure and combine it with fertilizer to maintain good soil quality, but these aren't the only potential feedstock sources from farms. Annabel also mentioned that some biomass may be able to be obtained from the forests around the farms. These forests are usually not managed even by the farmers which means they would possibly be willing to give up that biomass for biochar production.

Residential Sources

During our interview with Elfi Blackburn and Catherine Pepper of the Maitland City Council Waste Management, our team inquired about the current waste practices and the established green bin systems utilized in the Maitland, Lake Macquarie, and Newcastle City Councils. Our team wanted to see if there was a potential to use this green waste for either our proposed medium scale or large scale projects; however, we learned that waste collected from the green bins is in high demand. We were told that this waste is under contract for several years, and there is already a lot of competition for when the current contract expires.

Policy Changes Regarding Waste

Policy changes to reduce environmental impact have been proposed in several areas, including waste management. Our interview with Elfi Blackburn and Catherine Pepper gave us insight on the upcoming changes that the Maitland City Council is making regarding the reduction of waste that goes to landfill. As of right now, the council diverts 35% of their waste from landfills but has pledged to increase that number to 80% in the next 10 years. Given that Maitland's population is projected to increase from 70,000 to 110,000 by 2040, this could necessitate new and innovative waste disposal solutions. Jonathan Wood of the Hunter Joint Organisation also had input, reporting that New South Wales is aiming to eliminate emissions from landfills as a whole over the coming years, but are still developing their strategies to do so effectively. As the area works to reduce landfill waste, the potential for these waste streams to be diverted towards alternative disposal solutions such as biochar increases.

Small Scale

Use of small scale biochar solutions are quite rare as the technologies for home biochar production are still undeveloped on a wider scale, but we were able to connect with a user of such a system in Australia. Hunter resident Kerry Bowen utilizes a system known as a Kon Tiki flame curtain pyrolyzer, which can produce biochar from burnable materials relatively easily. He told us that he has burned dried wood from fallen trees on his property as well as manure, and he has used the produced biochar in his garden. He keeps the machine in his backyard, and it doesn't require much maintenance or storage as it is made rather simply. Some downsides to this system were that it was quite smoky as he learned to properly use it. This doesn't present a large environmental problem, but smoke during biochar production with this system does mean it is running less efficiently than it could be. The smoke was also quite annoying to his neighbors, which could be a potential hurdle in encouraging widespread use. He also reported that it wasn't necessary to run it very frequently to produce the amount required for his gardening purposes. According to further research only about a 5-10% mix of biochar with soil is typical for home gardeners (NextChar, 2017), so smaller gardens require a very small amount.

Medium Scale

We were able to find more support for our proposed medium scale solutions among the stakeholders that we interviewed. David Holmgren, a leader in the permaculture field, voiced several ideas in support. When processing the larger amounts of feedstock with the technologies at the medium scale, heat from the process can be captured and reused. Some of his ideas included reusing the heat to dry the incoming feedstock before it is used, increasing the efficiency of the process, as well as routing the heat to local greenhouses in order to extend the length of the veggie production season. While local greenhouses don't necessarily exist in the councils, they could be established in order to increase the sense of community surrounding this biochar facility. He also envisioned putting an emphasis on the processing of wood waste from forests, which would significantly reduce future fire risk, and this could further serve as a powerful community engagement tool. One of the important details of our medium scale was the curb-side collection system, which Elfi Blackburn at Maitland City Council Waste management told us has proven to be a very effective tool for collecting the kind of organic waste that we could utilize in this medium scale system as well.

Large Scale

Processing biochar on the large scale presents us with some more opportunities that aren't really available at the smaller scales, as some of our contacts informed us. The heat produced on a large scale could be harnessed for larger manufacturing such as aluminum and canneries, Annabel Kater of Australian Sustainable Timbers told us. When we further discussed this with Tim Askew at Hunter Joint Organization, he added that the heat energy could be utilized for refrigeration purposes, whether it be for cold storage or other similar options. Mr. Askew also reported that the gases produced as a byproduct at this scale could be used to produce electricity, which could feed back into the local grid and reduce the amount of coal power required in the area.

Challenges

We asked each of our interviewees if they foresaw any glaring challenges that our proposed biochar solutions would have to overcome, and they had some interesting responses for us. We presented farmers as being the impactful users of biochar due to the large areas of land they already fertilize, but Tim Askew told us that convincing them to incorporate biochar into their established system could prove problematic. He informed us that the economics would have to be correct for it to fit into their cost per hectare budget, and that the added value proposition would have to be significant for them to alter their systems. This would be especially challenging given the lack of long-term studies on the impacts of biochar in agricultural settings. He also added that a universal issue with biochar and biofuel production systems is that much of the technical expertise comes from overseas and that the current travel restrictions with COVID-19 make it challenging to establish new projects currently.

A recurring theme during several of our interviews was the extensive transportation requirements that a large scale plant would entail. Jonathan Wood discussed that the large scale plant seemed too far-fetched due to the extensive costs and environmental strains that the transportation would bring, and Joe Herbertson echoed part of that sentiment, saying that while the feedstocks are everywhere, that also means that they must be collected from everywhere. The final problem that would need to be dealt with is properly marketing this project. Tim Askew told us that that representation needs to be improved around technologies such as biochar and renewables. We heard similar notions from Joe Herbertson, who told us that there are challenges with first proving the effects of climate change, then proving what methods can effectively deal with the identified issues, and then proving that char or other renewables are really the most effective way to move forward.

Community Support Survey

In addition to the interviews, we developed a survey that was distributed to residents of the Hunter Valley. This survey was designed to gauge residential support for a community-level biochar project by identifying gardening and waste disposal practices, as well as their interest in the differing scales of a biochar program that could be implemented into the Hunter as shown in Table 4. Screenshots of our survey can be found in section A.

Table 4: Survey Questions

Question:	Answer Format:
1. What council in the Hunter do you reside in?	Multiple choice, councils listed
2. Do you have a home garden or is there a community garden near you that you participate in?	Yes/No
3. How do you handle excess food waste or garden plant waste in your home or community garden?	Compost, Trash/Garbage/Rubbish, Other (please elaborate)
4. If green waste from your home could be used to make biochar, please rate the following options from a scale of 1 to 4 (1 is least preferable, 4 is most preferable). Please only use each number once.	Options are described in detail under "Rating the Scales"
5. Any comments or suggestions based on the options above?	Short Answer
6. On a scale from 1 to 5, please rate your interest in composting, 1 being no interest, 5 being very interested	Rate 1-5
7. On a scale from 1 to 5, please rate your interest in recycling, 1 being no interest, 5 being very interested	Rate 1-5
8. Are there any ecological and/or environmentally friendly practices you partake in at home? (i.e. permaculture, sustainable agriculture, etc...) If so, please describe them below.	Short Answer
9. Are you interested in learning more about community programs to increase local ecological resilience that you could engage in?	Yes/No

We distributed this survey by utilizing Hunter council notice boards on Facebook. Each of these Facebook groups holds around 7,000 members each and we posted our survey to 11 different council groups. Additionally, our survey was sent out to environmental groups in the Hunter, who then spread the survey further which helped us gather more data. This could introduce some bias to our survey, but this community is likely to be the earliest adopters and supporters of biochar technology, so their input was important to our group.

When our allotted survey period was over, we had received 82 responses, with at least one response from each council. The breakdown is shown in Figure 12. While we didn't receive a large enough sample from each area to draw meaningful conclusions on a per council level, we were able to use the free response information given by people from those councils to inform some of our ideas.

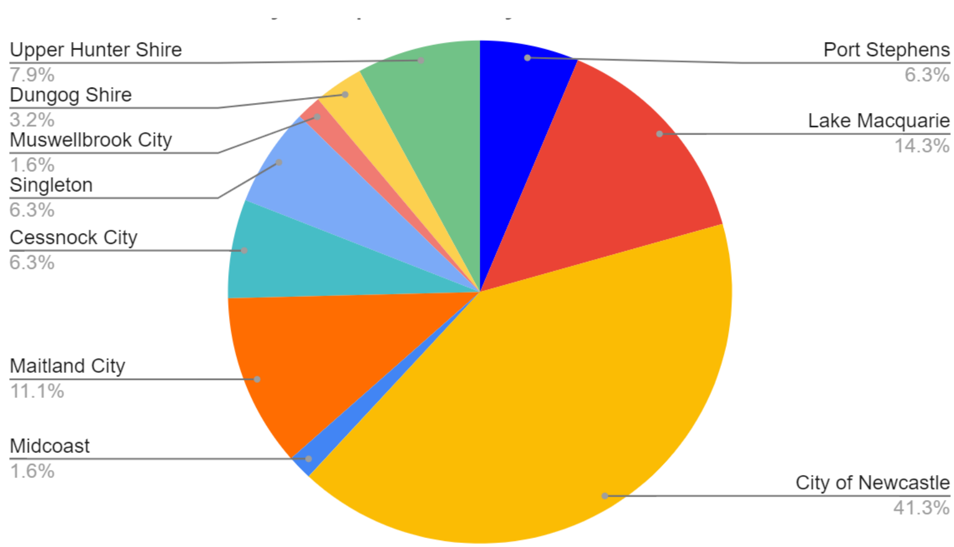


Figure 12: Location of Survey Respondents by Council

We first reviewed our survey data to see how many of the people we sampled gardened or participated in a community garden, and we found that 94% of respondents did in fact garden. While our survey is quite limited in terms of scale, it appears that, at least among these participants, that biowaste from gardens could be a potential feedstock. Additionally, the prevalence of community or home garden use indicates that there may be a potential market for biochar use as a fertilizer. Second, we examined whether residents were producing excess waste that could be utilized for biochar purposes on any scale, and whether these waste streams could be diverted for biochar production. Most of our respondents already dispose of their garden waste in biofriendly ways, such as mulching or processing with worm farms, both of which increase soil quality and keep waste from landfill.

Biochar can supplement those methods by capturing the emissions, however, so there could be potential in using those methods in combination with it. Roughly 6% of reported garden waste does go to landfill, however, which is a waste stream that we could potentially target for biochar usage. An important consideration in Figure 13 is that the green bin system is only currently available in Maitland City, Lake Macquarie, and Newcastle City Councils. With 65% of respondents being from those three councils and 49% of respondents utilizing this system we could see that this could be an effective system for green waste disposal, and this could be part of the large and medium biochar scales.

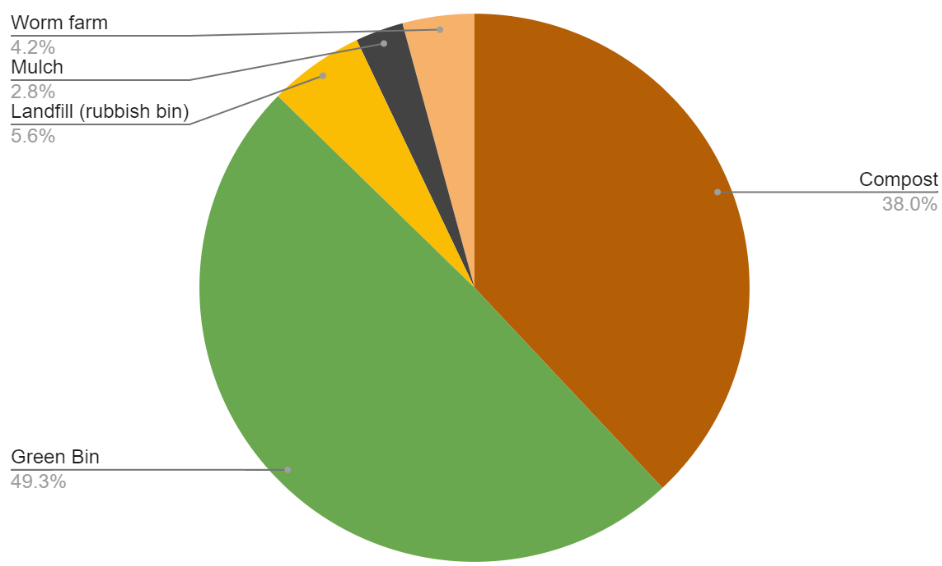


Figure 13: Breakdown of Garden Waste Usage by Survey Respondents

Rating of the Scales

Question 4 of our survey asked residents to rank four proposed biochar production options. The first was the small scale residential option, which was presented as "I would like to make biochar at home". This option would put all the responsibility on homeowners for their biochar production and usage. The second and third options were both regarding the medium scale in larger communities, and the two choices were "I take my green waste to a local community facility, and I take back the biochar for use in my own garden" and "The council collects my green waste and the biochar produced is used in council gardens and parks, and I can buy some biochar back for a small fee for use in my own garden". We split the medium scale options in order to further gauge how involved residents were willing to be in this kind of biochar process. The fourth and final option was a large scale solution; "My green waste is collected and taken to a biochar production plant in the Hunter where my green waste is turned into biochar and can be used by Hunter farmers and councils".

We found mixed levels of support for our small-scale biochar solution from comments and responses to question 4. As shown in Figure 14, the small scale had roughly 40 respondents ranked the small scale a 2 or below, with only 22 rating it as their top choice.

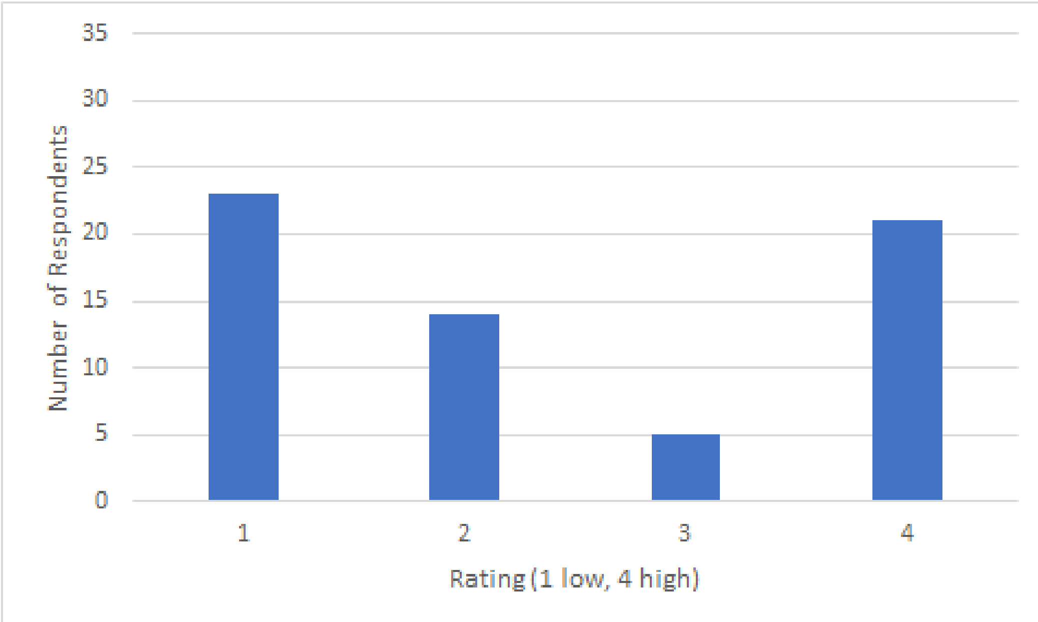


Figure 14: Rating of Small-Scale Biochar Solution

One City of Newcastle Resident was concerned that "Making Biochar at home would likely be hazardous due to the smoke produced. Also, hard to control", and another resident said that "I wouldn't generate enough in my small garden to warrant doing this myself". It seems that these residents weren't really interested in managing the system themselves, and didn't think that the amount of biochar they would need to produce would be worth the investment of the system. A resident with a smaller garden wouldn't really benefit from having their own biochar kiln, because small amounts of feedstock and thus small amounts of produced biochar would make it difficult to justify the investment, so they would likely benefit more from a medium or large scale where they don't have to handle production themselves. However, a Port Stephens Council Resident said they'd "like to participate in a pilot" and a City of Newcastle Council Resident reported "I've been making my own for a while".

The green bin system, while serving as a barrier for the small-scale biochar solution, could prove to be an effective tool at the medium scale. When we considered the options for a medium scale solution, we envisioned both an option where waste is collected curbside similar to the existing green bin concept, and also one where residents could bring their waste to a central location. When residents ranked our proposed options, they ranked the collected option overall higher than bringing their own waste, as shown in Figure 15. Some concerns from Newcastle City Council residents were that they "really haven't got time to transport it" and they "are getting older and busy enough, so don't want much extra to do", demonstrating that having councils collect green waste would be a much more popular and thus effective method.

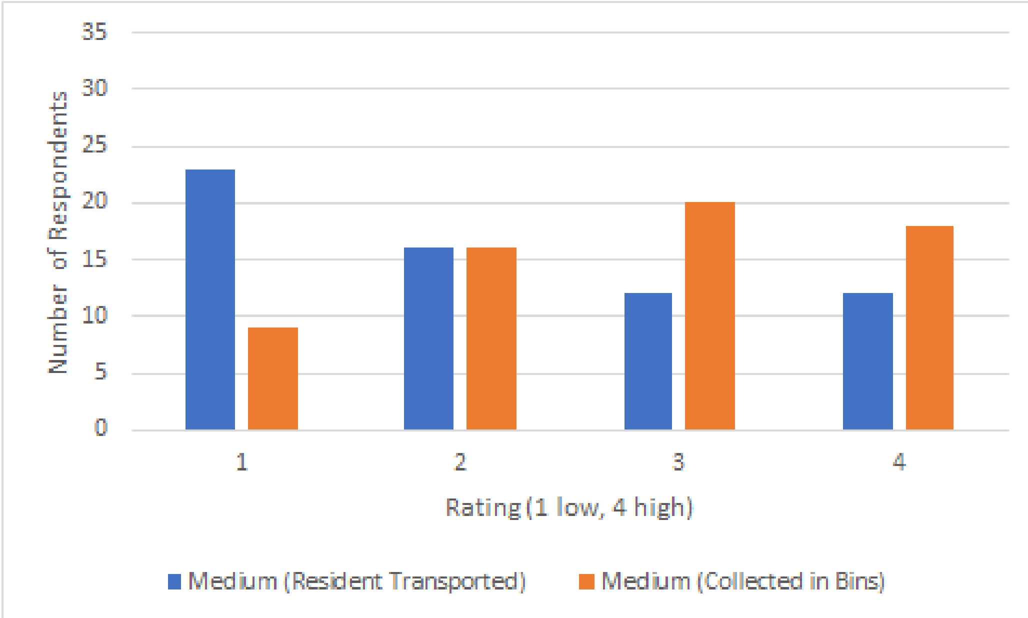


Figure 15: Rating of Medium Scale Biochar Options

However, this option may not be viable for more rural councils such as the Upper Hunter Shire Council. The councils who have enacted the green bin system are more urban and have a more centrally located population. In contrast, one Upper Hunter Resident reported that they "live on a property 30kms from town" noting there is no council collection system and it was "practical to take to a facility".

The large scale biochar production option was by far the most popular among survey respondents (Figure 16). Many of our respondents regard the medium and large scales as more efficient, mentioning the larger scale of production than the other options. The large scale would also open up access to stakeholders that would utilize greater amounts of biochar such as the agricultural industry and the council governments themselves.

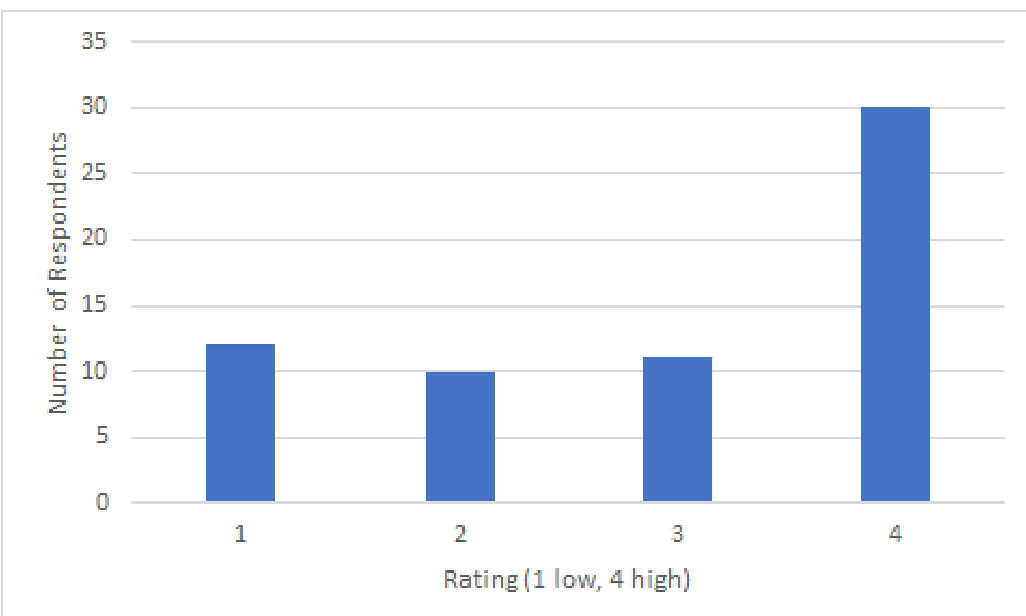


Figure 16: Rating of Large Scale Biochar Options

Discussion of Survey & Interview Results

Our survey and interview responses varied due to different environmental and economic factors as well as the varying community preferences. Each scale has their own benefits and drawbacks, which proves that creating a biochar production facility that fits the needs of stakeholders and the community is not one that can be solved by just looking at one specific solution.

Table 5: Benefits and Drawbacks of Each Scale

	Small	Medium	Large
Benefit	- No transportation - Educated and engaged homeowners	- Good community support - Best scale for pyrolysis technology	- Most community support - Most economic sense - Maximises biochar potential
Drawback	- Low community interest - Wood vinegar and syngas lost - Technology has a learning curve	- Some transportation - Competition with green bin system	- Lots of transportation - Pyrolysis tech less suitable

Small Scale

Based on the results of both the interviews and surveys, the small scale option for biochar production doesn't seem to be a very popular option. Our conversation with Kerry Bowen indicated that home biochar production seems to be more of a labor of love than a practical solution from an economic standpoint. The personal investment into a biochar system seems to be high, and the smoke created during the learning process could dissuade urban use of systems similar to the Kon Tiki (Figure 17). However, that system could be better suited for use in the more rural councils where central collection would be challenging. It is also probable that residents would have more land to draw biomass from and more space to use the biochar.

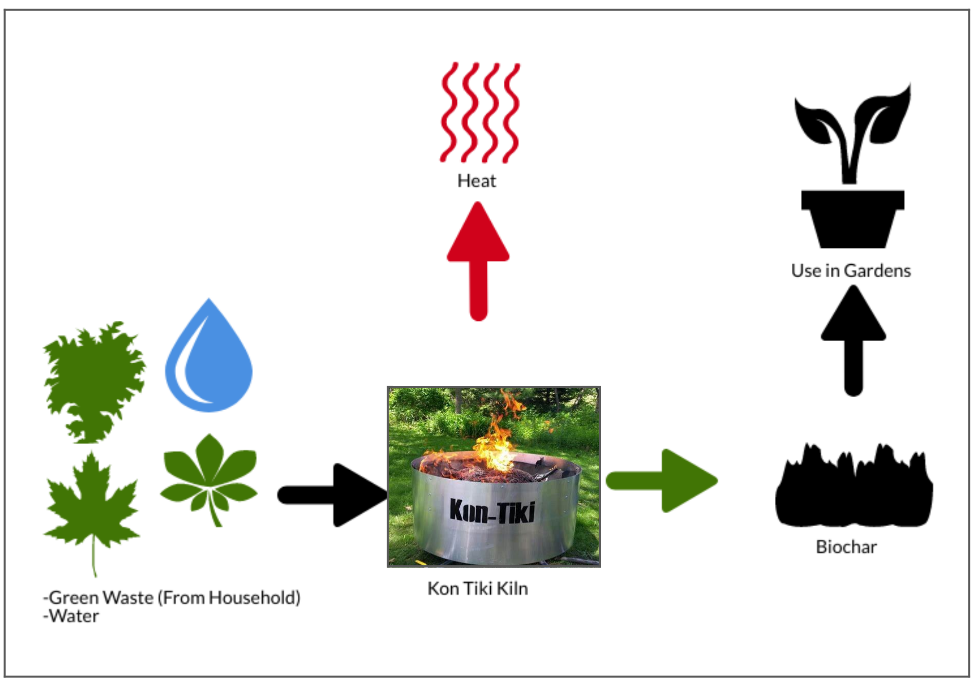


Figure 17: Kon-Tiki Biochar Kiln (Finger Lakes Biochar, 2020)

Having more space would also reduce the concerns of the smoke from biochar production, as well as the fire risk because the machine could be located farther away from buildings than in a more urban setting. One of these systems could feasibly serve multiple interested homes, which in and of itself starts to point more in favor of the medium scale option because it would serve a larger number of people. The small scale overall seems to be a better option for residents who are already interested in environmental sustainability, rather than being a compelling option or necessity for the average person. However, there are some further complications among even this audience. Given the prevalence of composting and other sustainable practices among our survey respondents, it could prove to be challenging to convince this audience to transition from practices that they're already comfortable and familiar with to a new and less proven technology.

Medium Scale

The medium scale option seemed to have a lot of potential for many communities in the Hunter and seemed to have support from both the surveys and our interviews. The survey respondents ranked the medium scale lower when the waste had to be gathered and brought in by the residents but was viewed more favorably through the council collection system. This is mainly because many respondents wanted to avoid additional work in their already busy routines. Our conversations with waste management experts shed light on the success of the green bin systems in the councils where it has already been established. The communities that offer the green bin system overall dispose of the correct types of waste in the bins which keeps the contamination rates low, indicating that with the proper messaging a biochar project could utilize a similar system and successfully gather residential garden waste as a feedstock. This could also be important for a large scale project. However, the existence of these green bin systems in Newcastle City, Maitland, and Lake Macquarie Councils does create a barrier for residential green waste to be captured for biochar usage in those particular councils because that green waste simply isn't available. It could be possible for a biochar project to gain the contract for this waste once the current one expires, but that could prove to be challenging. A breakdown of this process is seen in Figure 18.

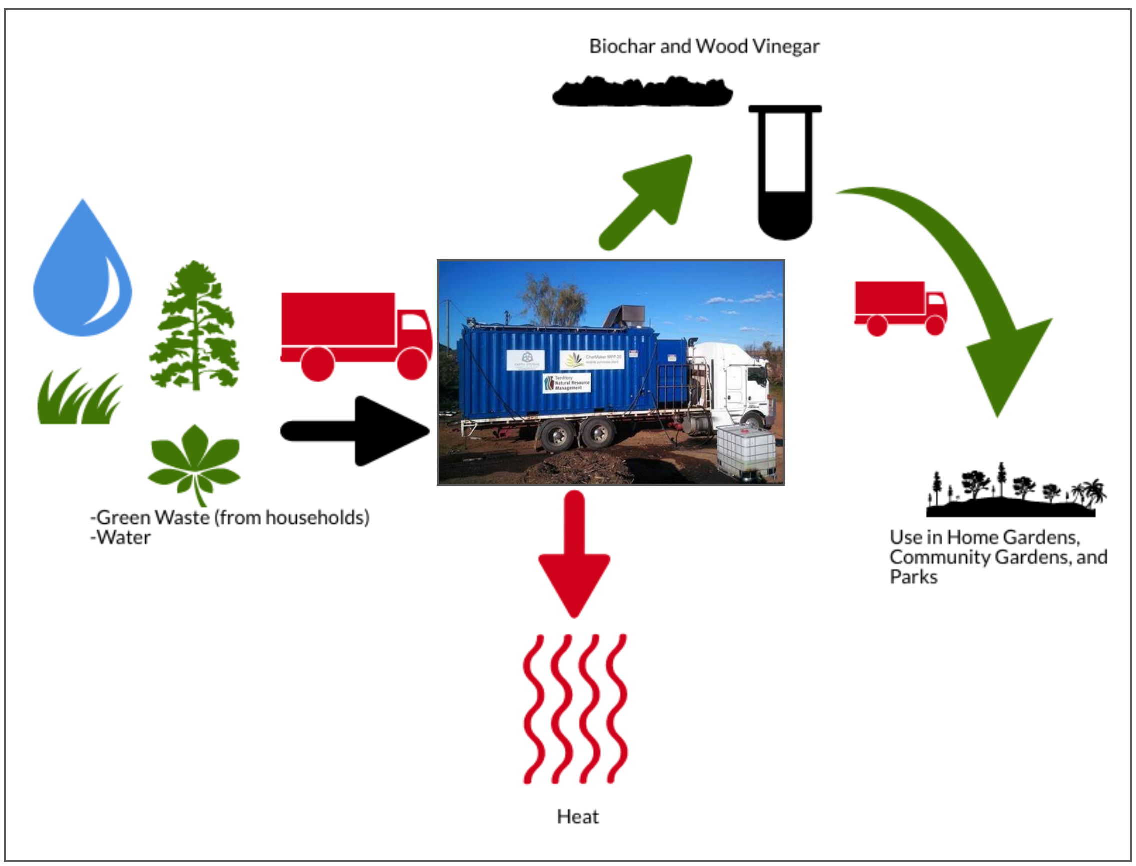


Figure 18: Medium Size Scale Pyrolyzer

Large Scale

After our interview and survey process, our team had a lot of conflicting information regarding the large scale project. Some viewed the large scale option as being the best based on an economy of scale, but our interviews with experts revealed that this may be an incorrect assumption given the increased cost and impact of transportation over the much larger area. The increased availability of the biochar would lower prices thus making it more accessible across a wider area. However, this concept was rebutted by some of the people we interviewed, who claimed that the pyrolysis process itself is very scalable, so the only real difference would be in the impact of transportation on both the costs and the environmental effects. There are many other challenges with a large scale plant, such as sourcing green waste across the entire Hunter and managing a large transportation network that would create large amounts of pollution. Capturing waste heat would also be a large concern, because releasing all of the excess energy into the environment would be an ecological issue. To use the excess heat effectively, it would need to be diverted to a location very close to the plant, for example pairing the biochar plant with a nearby smelting or canning plant. However, this could prove to be very challenging logistically. Another option would be to utilize the heat to produce electricity to power the pyrolysis process, or even to further dry the feedstock to increase the efficiency when processing it. In addition to our interviews and surveys, we also gathered data and conducted a Life Cycle Assessment to estimate the environmental costs and benefits of each scale which will be detailed in Chapter 3. A breakdown of this process is seen in Figure 19.

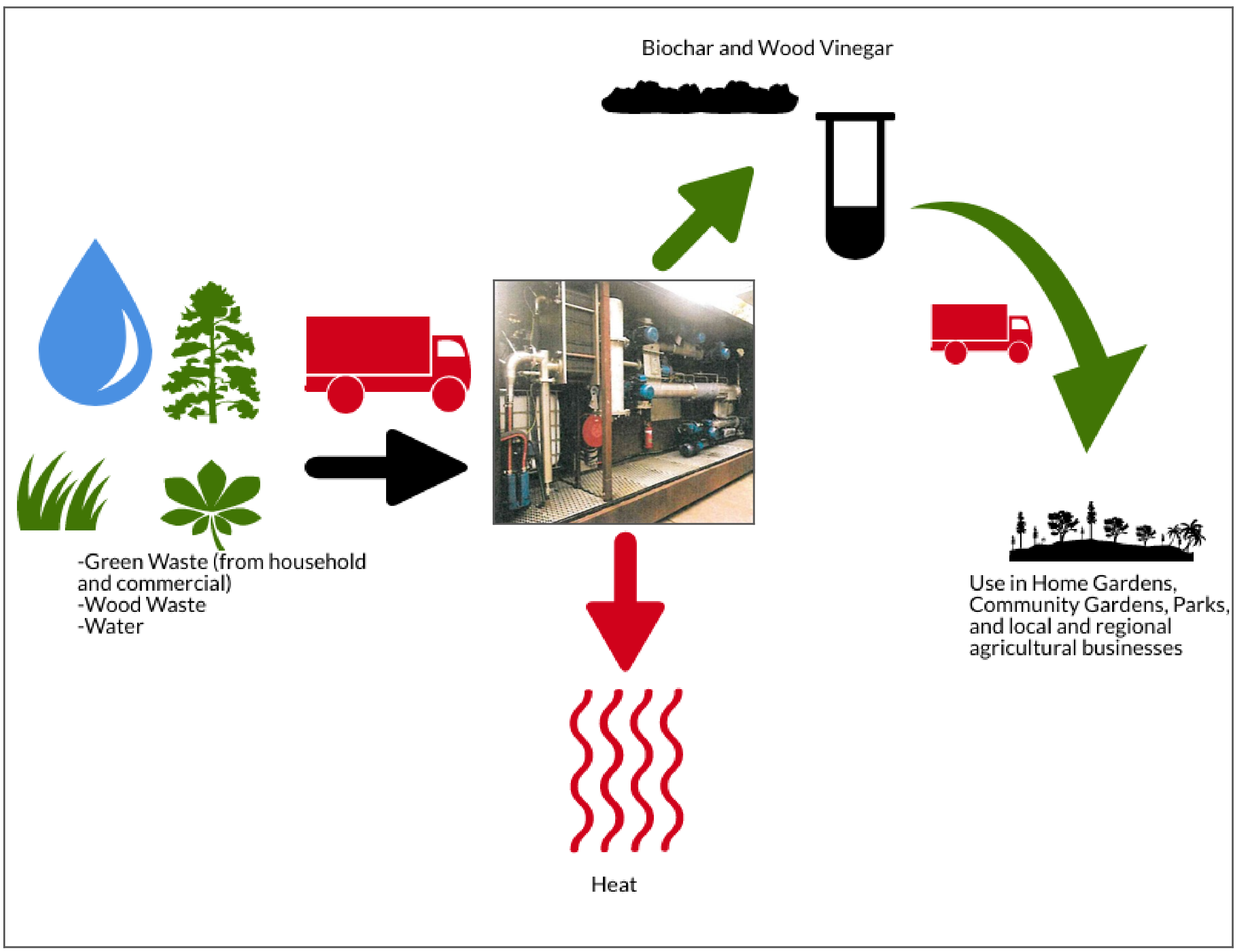


Figure 19: Large Size Scale Pyrolyzer

Given these considerations, we outlined the following components of a potential small, medium, and large scale system. Table 6 summarizes the key points of each system, as well as pros and cons that we identified through our interviews and survey.

Table 6: Inputs & Outputs

Scale	Inputs	Outputs	Pros (Benefits, Costs)	Cons (Impacts, Costs)	Relevant Survey Comments
Small	-Green Waste -Water -Pyrolyzer	-Biochar (for home garden) -Heat	-Empowerment of doing it at home -Connection to individual impact -No transportation	-Lowest community support -Byproducts potentially wasted	- “I would love to be able to get benefits for my garden.” - “I've been making my own for a while.” - “I'd like to participate in a pilot.”
Medium	-Green Waste -Water -Pyrolyzer -Transportation (council collection)	-Biochar (for homes, community parks) -Heat -Wood Vinegar	-Some community support -Byproducts can be used more easily	-Emissions from transportation -Transportation costs -Competition with green bin systems (some councils)	- “As long as we are removing compostable materials from landfill and resultant methane production I'm happy.” - “Using biochar across council would be a best use of the resource because it will benefit the wider community”
Large	-Green Waste -Misc. Wood -Water -Pyrolyzer -Transportation (council collection) -Transportation (to main plant)	-Biochar (for homes, parks, farms, forestry) -Heat -Wood Vinegar -Transportation (plant to councils) -Transportation (council distribution)	-Best efficiency for biochar production -Byproducts can be used more easily	-Emissions from transportation -Heavy transportation costs -Competition with green bin systems (some councils)	- “I think that it would be best done at at government level, I can't see the energy usage required to make biochar being justified otherwise

In the following chapter, we assess the environmental and economic benefits at each step of the process involving these components.

Chapter 3: Life Cycle Assessment

Any product, including an eco-friendly one like biochar, has positive and negative impacts, whether it be environmental, social, or economic, and it is important to measure those impacts. Life Cycle Assessment (LCA) is the "analysis for reporting potential environmental loads and resources consumed in each step of a product or service supply chain" (Caro, 2019, pg. 254). LCA is done through examining every phase of the life cycle of a product. Life cycle includes: raw material extraction, manufacturing and processing, transportation, usage and retail, and finally, waste disposal. The technique we used to analyse this cycle is known as *Cradle to Grave.* We selected this technique in order to analyse the entire life cycle, because biochar is not recycled, but rather is "disposed of" through its intended use in soil. Cradle is the start of the product; the very first step in the life of the product, and Grave refers to when the product is disposed of. These cycles can be seen in Figure 20.

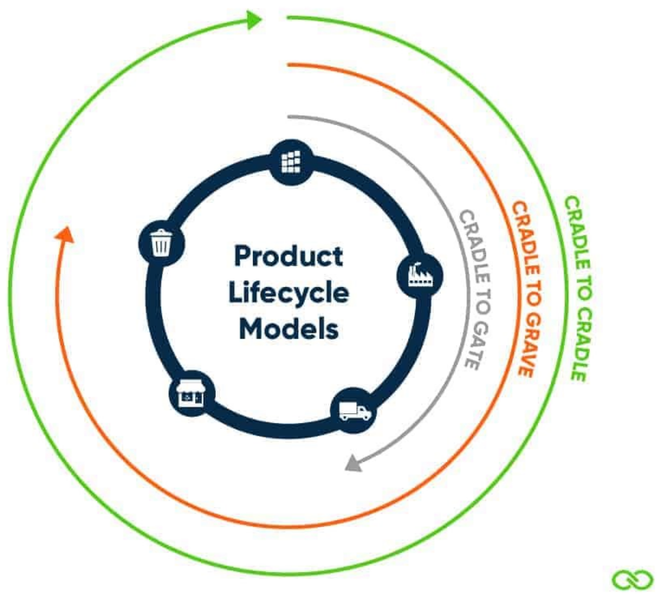


Figure 20: Product Lifecycle Models (Ecochain, 2020)

LCAs have 4 stages: defining the goal and scope of the analysis, life cycle inventory (LCI), the life cycle impact assessment (LCIA), and lastly the interpretation of results.

Goal and Scope

The first step in LCA is identifying *Goal and Scope.* The purpose of the study is to support decision making about the appropriate scale or scales for a biochar system in the Hunter. Aimee Mehan and Beyond Zero Emissions will use these results when moving forward with this project. The Hunter Joint Organisation and Annabel Kater of Australian Sustainable Timbers are also interested in the results. These stakeholders want evidence for the feasibility of a biochar hub at each scale: small, medium, and large.

While our LCA will yield useful information, there are limitations to our study. Life Cycle Assessments are capable of going into great detail, but given the short time frame for this project, we chose to do a "scoping" LCA, which is a simplified version. It covers the entire life cycle of biochar production from harvesting specific biomass to processing and transporting it, but it does so by providing estimates through the collection and analysis of generic data and standard modules for energy production. We also focused only on what we saw as the most relevant environmental aspects/stages of the life cycle. Our findings are thus a crude estimate but are still an important first step in estimating environmental impacts as a whole.

Environmental impacts can be measured in terms of upstream flows (inputs) or downstream flows (outputs) of the system by setting up a functional unit of analysis. This unit is the parameter in which results are presented. We decided to focus on upstream flows, specifically the amount of biomass or green waste that might be collected and what it would take to process the material at each scale. Our functional unit was green waste per tonne. This means that all the benefits and drawbacks we report are measured based on the assumption that one tonne of green waste is used. Another important part of the LCA process is to define the system boundaries. In this case, the team only considered the life cycle of biochar (Figure 21) from the raw material extraction to its final disposal, or Cradle to Grave.

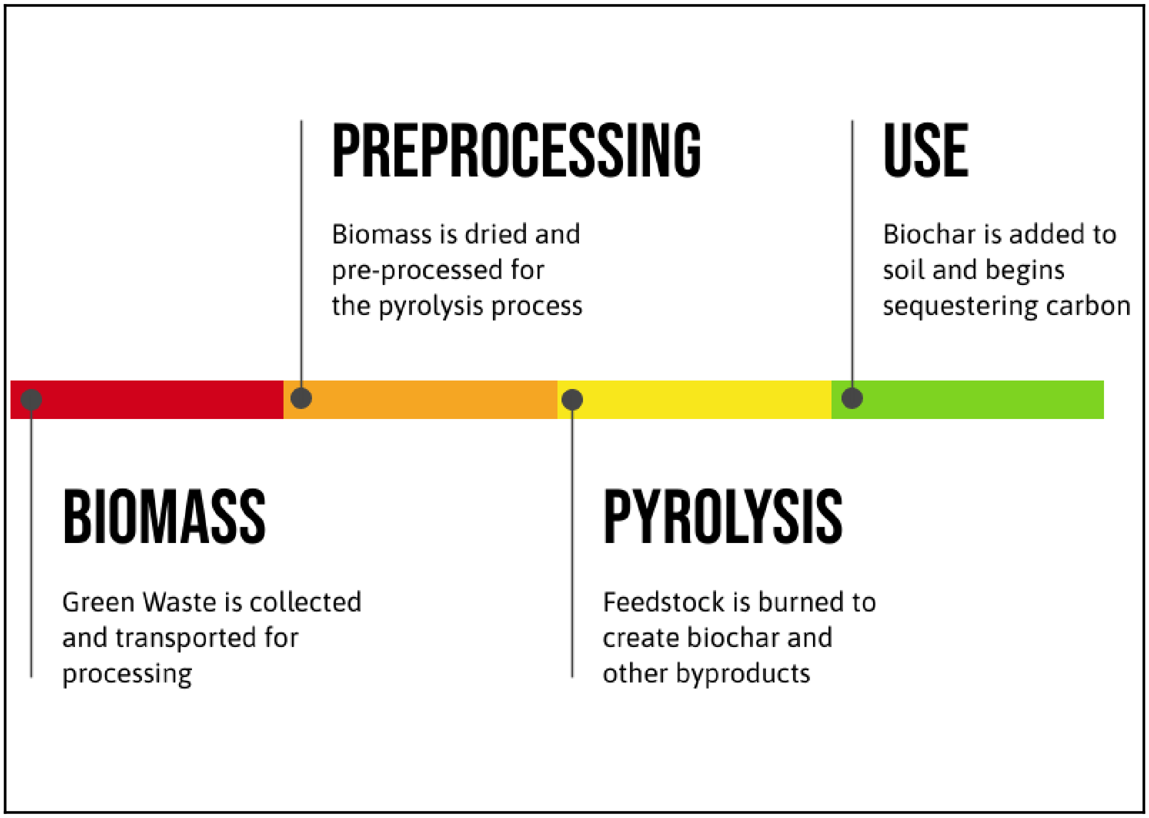


Figure 21: Life Cycle of Biochar

Life Cycle Inventory

The next step in the LCA process is Life Cycle Inventory. This step is typically seen as the most labour intensive as this is the data collection portion of LCA. The inputs and outputs are quantified at every point in the production of the product. The inputs are the biomass used, materials/energy required to process the raw materials, and transportation when required. The outputs are the biochar and wood vinegar. Each of the inputs and outputs have emissions related to them. Our team relied on published databases and general assumptions from our interviews with stakeholders to obtain the required information on waste, travel distances, and biochar production efficiency. We made assumptions about: the amount of biomass processed, of the type of pyrolysis machine that would be used at each scale, its biomass to biochar conversion rate, and what emissions and byproducts would result from this process. Our team relied on existing databases of information researched by organisations, or information from existing case studies. A waste database built by the Hunter Joint Organisation (Supplemental Materials Section E) gave us approximate tonnage numbers of waste broken down by council in the Hunter. We confirmed the estimated accuracy of these numbers when we spoke with Catherine Pepper and Elfi Blackburn of the Maitland City Council Waste Management department. These numbers were then plugged into our LCA as the amount of green waste that might be available for processing at the large scale. It is important to note that three councils already collect green waste and dispose of it through composting.

This waste is under contract, so there is potential for a biochar project to take over this contract in the future, but it is unavailable for this use at time of writing. They also provided information on the annual amount of green waste produced in Maitland City Council, as well as the average waste per person, which helped us provide estimates for the small and medium scales. They also provided us with travel distances for the waste collection trucks. The exact numbers can be found in Supplemental Materials Sections C and D.

To find the costs and environmental impacts of the materials used to make each pyrolysis machine, as well as the efficiency of each, our team researched product information from the internet and asked the experts we interviewed. The inputs and outputs of our biochar systems can be seen in Figure 18 on the next page. The small scale pyrolysis machine was assumed to be a Kon Tiki Kiln (*Kon-Tiki Kiln | Finger Lakes Biochar*, 2020), the same type of machine used by our interviewee Kerry Bowen. The Kon Tiki Kiln seemed to be appropriate for the small scale project due to its price, size, and efficiency. For the medium scale, our team used a Mobile Pyrolysis Plant as reference (Bioenergy Earth Systems, 2020). This machine seemed appropriate due to its flexibility in transportation as well as its size. Lastly, with the help of Joe Herbertson, we used data from The Crucible Group's upcoming pyrolysis machine to account for the large scale machine. Even though most of the information is still proprietary, we acquired reference numbers for its size and estimated efficiency. These numbers can be found in supplemental materials section B.

We also needed to measure the environmental impact of transporting green waste to the production facility. In the large scale waste was transported from homes to central collection points within each council, then from this central point to Muswellbrook. The medium scale was only transported from homes to a central facility, and the small scale required no transportation at all. Estimated distances were found with the help of Catherine Pepper and Elfi Blackburn. They provided us with details of the Maitland City Council waste collection system. This included the travel distances within the council to collect all the waste from green bins over a two week period. Our team was able to use this information to estimate the distances travelled within other councils by comparing Maitland City Council's area to the distance travelled by collection trucks in the council. We did this by dividing the distance traveled in Maitland by the area of the council to get a kilometers travelled per square kilometer number, then we multiplied this by the area of the other councils to estimate the travel distances within them. Overall details, such as the method of transportation and capacities, were obtained mostly by using standard equipment. We assumed that 21 tonne capacity garbage trucks would be used to collect waste within each council. Even though our team's assumptions might vary from what is practiced, this information helps provide a reliable comparison between the net impacts of the different scales.

Life Cycle Impact Assessment

The next step in LCA is the *Life Cycle Impact Assessment*. This is the point where we measure the environmental impact of each step in the production of biochar. One can look at a range of impacts: human toxicity, global warming potential, ecotoxicity and more. We limited our analysis to global warming impact. Each step of the process was analysed for net greenhouse gas emissions. It is very common for people to refer to greenhouse gases as only carbon dioxide; however, there are other gases that contribute to this such as methane and nitrous oxide. Since we didn't want to ignore these other gases, we decided to use the category "carbon dioxide equivalent," or "CO2e". This measurement applies to all greenhouse gases and sets them all in the same unit (Brander, 2019). It allows for compositions of several gases to be paired together and be easily measured.

In order to obtain data on carbon dioxide equivalents and organise it properly, we utilised the program SimaPro, paired with Microsoft Excel. SimaPro contains data on sustainability reporting, carbon and water footprinting, and product design. The version we used had several libraries containing information on processes that our biohub would use. We used this to find all CO2e values and were then able to offset these against the total biochar sequestration value. We examined our biochar systems over a 30 year time frame in order to illustrate how impactful biochar production might be in the long term at each scale, seen in Figure 22.

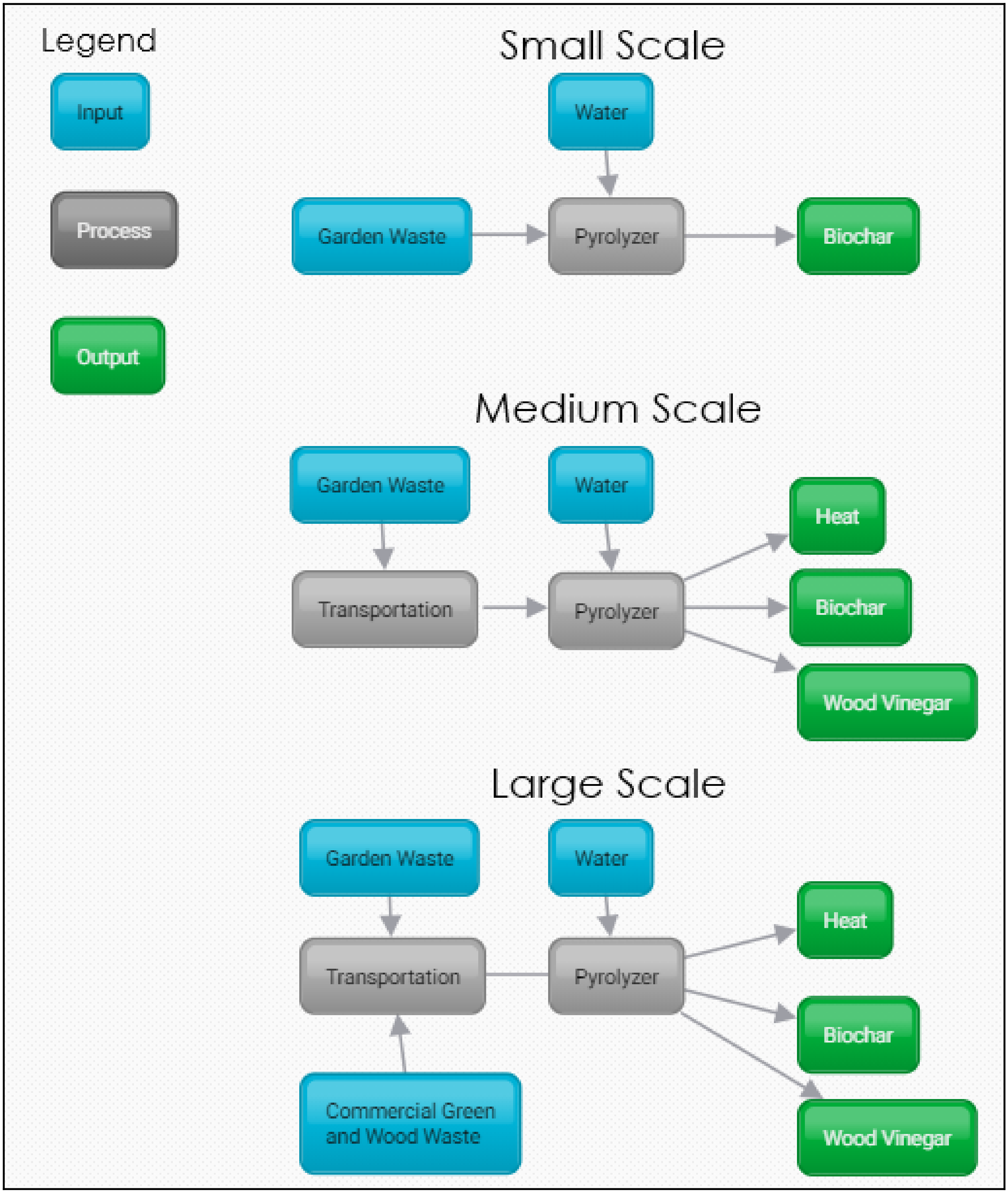


Figure 22: Biochar Inputs and Output

Small Scale Results

From our research and interviews we found that processing in the Kon Tiki Kiln pyrolysis machine converts 100kg of feedstock to 17kg of biochar, a 17% mass conversion rate. This biochar is significantly less dense than the feedstock, as the ending volume of biochar is 40% of the volume of the green waste before processing. By using the yearly average green waste per household from Maitland City Council Waste Management, we calculated that a household would produce roughly 15,000kg of green waste over 30 years. By using this data, we examined a single household processing their green waste using their own pyrolysis machine. In order to account for the impact of potential repairs, we doubled the impact of assembly. From this data and assumptions, we were able to calculate the amount of biochar that could be produced in a 30 year period, which was 2,550kg. We multiplied this by the amount of carbon sequestered per tonne of biochar over 30 years, which is 16.5413 tonnes of CO2, or roughly 0.55 tonnes of CO2e per year. We compared this to a past BZE land use report that estimated one tonne of biochar could sequester between 0.7 and 1.3 tonnes of CO2e per year (BZE, 2014). That gave us a net 42.17 tonnes of carbon sequestered in 30 years for this amount of biomass. This is the total amount of carbon that will be prevented from entering the atmosphere over a 30 year period, but to complete the assessment the carbon impact of the biochar production must also be examined. Since this part of the LCA is only looking at producing biochar at the small scale, this will have the least amount of carbon negative impacts. These impacts, as well as the net carbon sequestered, are summarised in Table 7 and visualised in Figure 23.

Table 7: Small Scale CO2e Impact Over 30 years

Input Component	**CO2e Impact of Input Component (Tonnes)**	**Output Component**	**CO2e Impact of Output Component (Tonnes)**
Green Waste 15,000 kg	N/A	Heat 81 Gj	-5.6
Water - 15,000 kg	-0.0002	Biochar 2,550kg	42.177
Pyrolyzer (Assembly) 692 kg	-0.7738		
		Net CO2e Sequestered (tonnes)	35.803
		Net CO2e Sequestered per Tonne of Feedstock (tonnes per tonne)	5.62

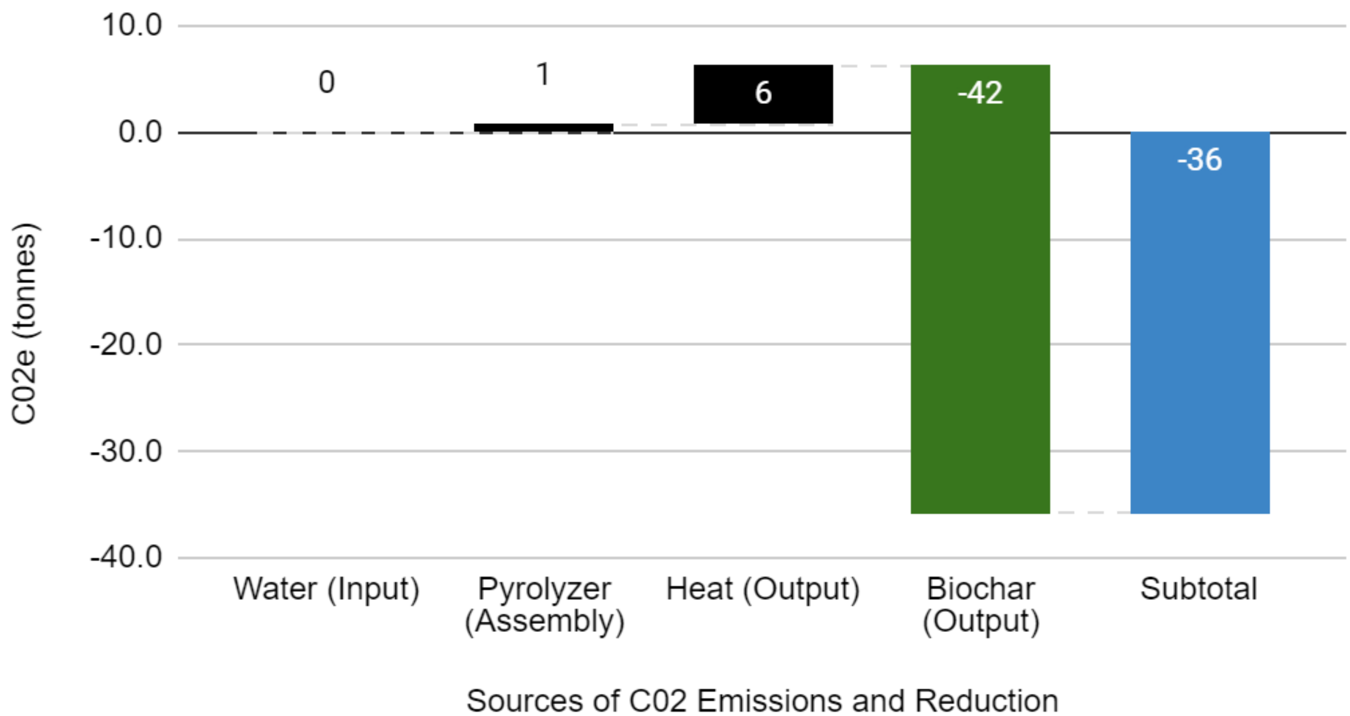


Figure 23: Small Scale CO2e Emissions Over a 30 Year Period

The CO2e of the water and the assembly for the small scale was found to be negligible as shown in Table 8 and Figure 23. A better way to represent this is seen in Figure 24. The water and assembly combined have only a 12.1% negative impact on the CO2e, when compared to heat which is 87.9%.

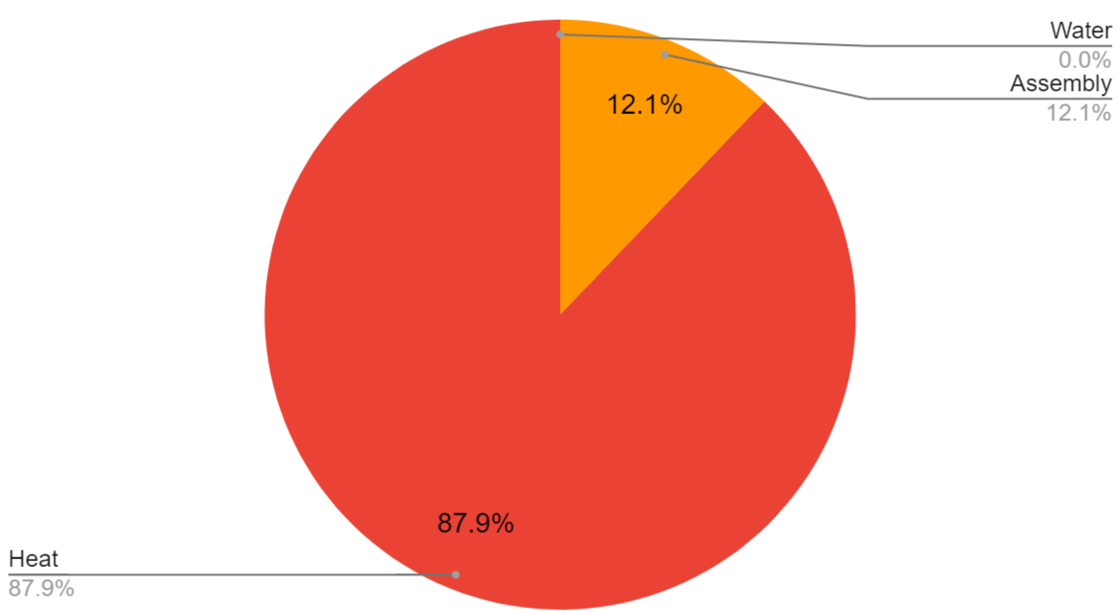


Figure 24: Small Scale Negative CO2e Impacts

Medium Scale Results

The medium scale has many similar components to the small scale, but there are added impacts through transportation, as well as increased requirements for running the machine. The conversion rate for biomass to biochar is more efficient than the small scale machine, with each 100kg of feedstock yielding 25kg of char, a 25% conversion rate. We used Maitland City Council as our model area for the medium scale because we had access to their specific green waste numbers, as well as the data for their existing green bin collection system. We made our estimates based on one pyrolyzer located near Maitland City. This gave us a detailed travel distance breakdown, as well as the model of trucks they utilise to give us accurate emissions numbers. Our transportation input is their yearly distance traveled collecting green bins, whereas the transportation output required to redistribute the biochar is reduced based on the reduction in mass of the biochar after production. The calculations are the same to calculate carbon sequestered as from the small scale, but using the biomass numbers seen in Table 8. The only new consideration for output in the medium scale was the wood vinegar, but it's CO2e impact is negligible. Despite not having a direct environmental impact, wood vinegar can have benefits including increased soil quality and crop yields, so we count this as a beneficial byproduct. It also has significant monetary value if processed and marketed correctly. The overall impacts, as well as the net CO2e sequestered over 30 years, are reported in Table 8 and visualised in Figure 25.

Table 8: Medium Scale CO2e Impact Over 30 years

Input Component	**CO2e Impact of Component (Tonnes)**	**Output Component**	**CO2e Impact of Component (Tonnes)**
Green Waste 137,580 tonnes	N/A	Heat 275,160 Gj	-19,023.4
Water 17,198 tonnes	-3.6	Transportation 1,083,160km	-1,332.29
Pyrolyzer (Assembly)2 tonnes	-1.31	Biochar 34,395 tonnes	568,938
Transportation 3,249,480km	-3996.86	Wood Vinegar 34,395,000L	N/A
		Net CO2e Sequestered (tonnes)	18,321.86
		Net CO2e Sequestered per Tonne of Feedstock (tonnes per tonne)	8.58

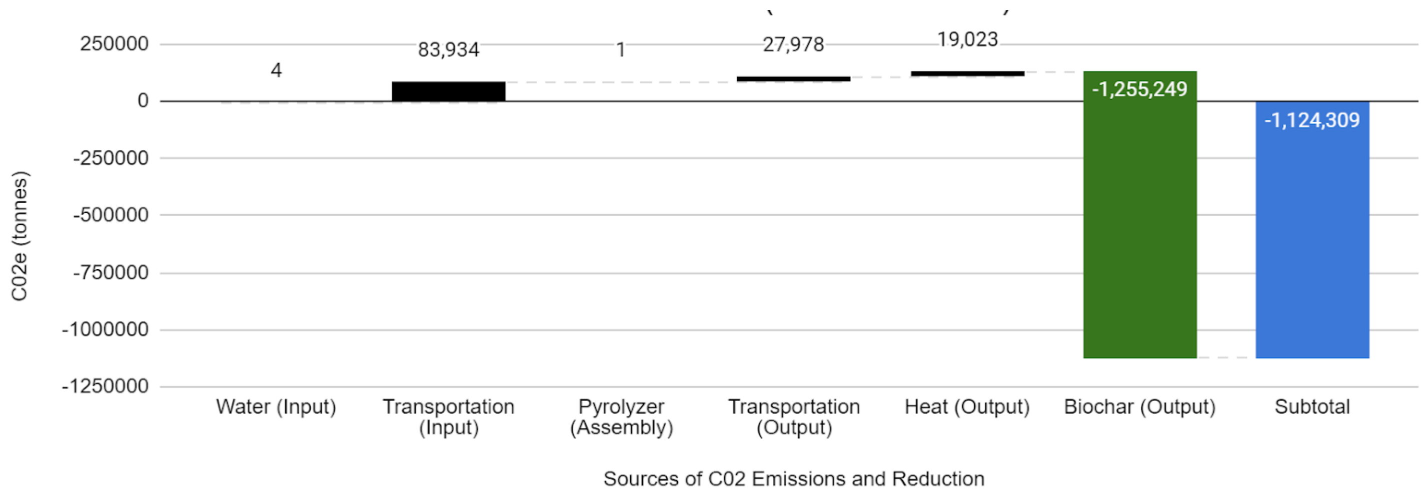


Figure 25: Medium Scale Negative CO2e Impacts

The CO2e of the water and assembly of the pyrolysis machine was found to be very negligible as shown previously in Table 8 and Figure 25. A better way to represent this is seen in Figure 26. Both the water and assembly have almost 0% negative impacts on the CO2e when compared to transportation and heat which are 85.5% and 14.5% respectively.

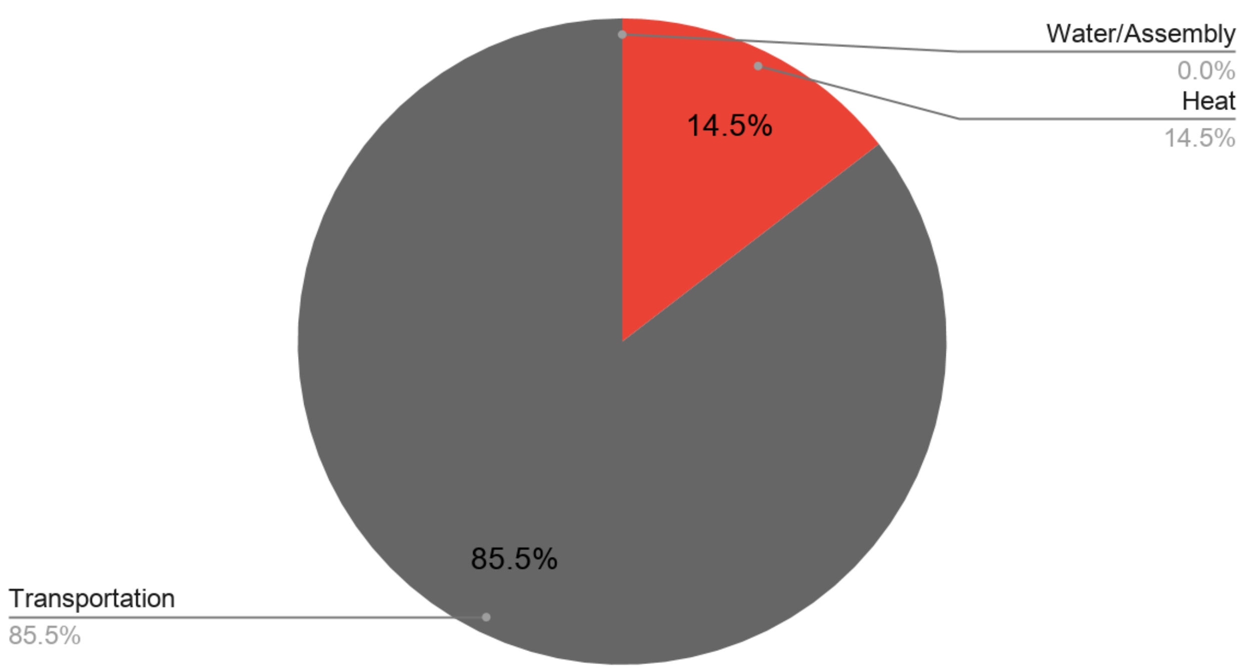


Figure 26: Medium Scale Negative CO2e Impacts

Large Scale Results

The large scale biochar production system was modeled to encompass each council in the Hunter for the purpose of this analysis. Waste numbers for each council were obtained from a Hunter Joint Organisation study on waste flow in the Hunter, summarised in Supplemental Materials Section E. We were unable to obtain the exact distances trucks would need to travel as we could only obtain numbers for Maitland City Council, but we estimated the distance for each council by comparing the area of Maitland to that of other councils and scaling our distances based on the ratio of their sizes. The biochar production efficiency increases to 30kg of biochar per 100kg of biomass produced, and the amount sequestered increases accordingly. The resultant sequestration, as well as the other relevant numbers, are reported in Table 9 and visualised in Figure 27.

Table 9: Large Scale CO2e Impact

Input Component	**CO2e Impact of Component (Tonnes)**	**Output Component**	**CO2e Impact of Component (Tonnes)**
Green Waste 2,255,820 tonnes	N/A	Heat 6,767,460 Gj	-467,873.8
Water 112,791 tonnes	-23.3	Biochar 744,421 tonnes	12,313,683.5
Pyrolyzer (Assembly) 8 tonnes	-14.38	Wood Vinegar 903,328,000 L	N/A
Transportation 289,946,760km	-356,634.6	Transportation 18,171,702 km	-22,351.3
		Net CO2e Sequestered (tonnes)	394,257.54
		Net CO2e Sequestered per Tonne of Feedstock (tonnes per tonne)	1.15

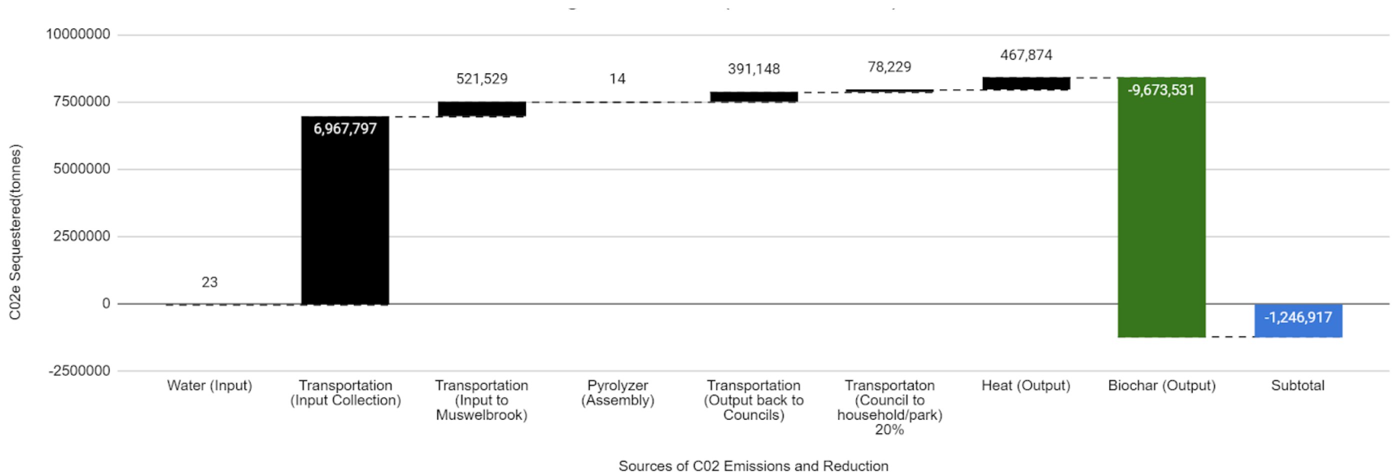


Figure 27: Large Scale Negative CO2e Impacts

For the large scale we had to account for a significant amount of transportation, therefore we found much higher levels of CO2e. However, that being said the amount of biochar produced was also much higher leading to significantly higher levels of carbon sequestration.

The CO2e of the water and assembly of the pyrolysis machine was found to be very negligible as shown above in Table 9 and Figure 27. A better way to represent this is seen in Figure 28. Both the water and assembly have almost 0% negative impacts on the CO2 eq when compared to transportation and heat which are 85.5% and 14.5% respectively.

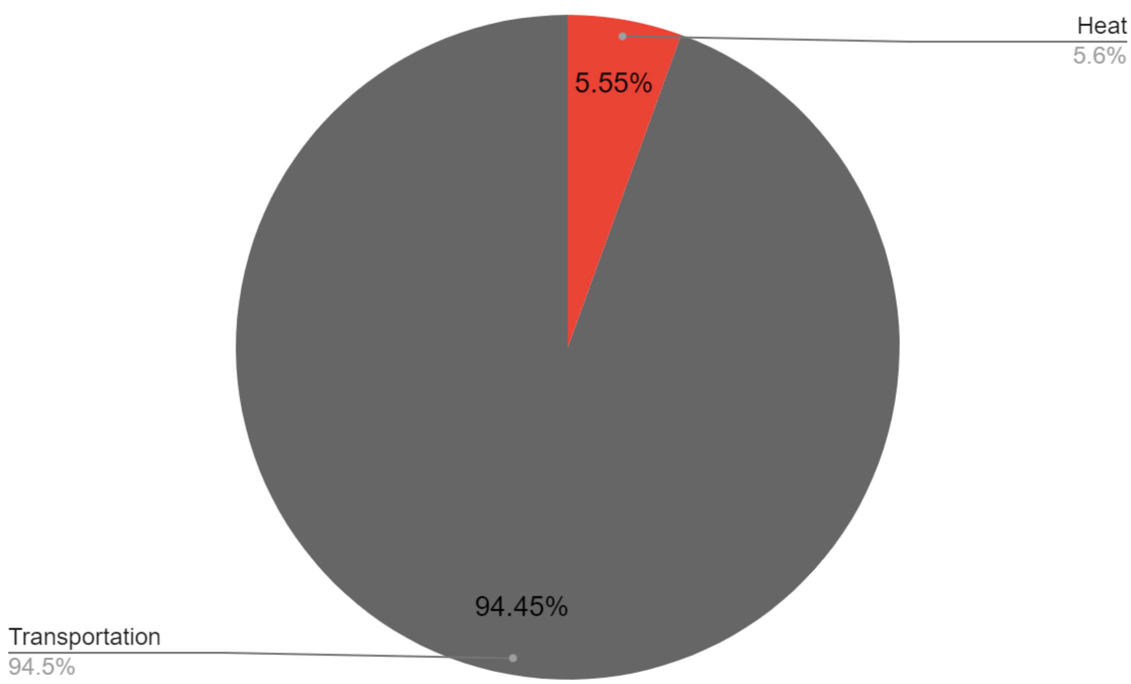


Figure 28: Large Scale Negative CO2e Impacts

Interpretation of LCA Results

The final step which can be performed at each portion of the analysis is *interpretation*. This is the point at which all the data that has been gathered is evaluated to summarise the environmental costs and benefits of the production process. Each scale of biochar production has very similar components, but the efficiency of the biochar production, scale of biomass processed, and amount of transportation required has a large effect on the net impact of the biochar produced at the end of the process. As Tables 7, 8, and 9 showed, the life cycle of each system would have a net positive impact on the environment. These estimates don't account for the other beneficial qualities of biochar, such as increased crop yields and increased soil water retention. As shown in Figure 29, the efficiency of the biochar production process increases as the scale is increased from small to medium, and medium to large.

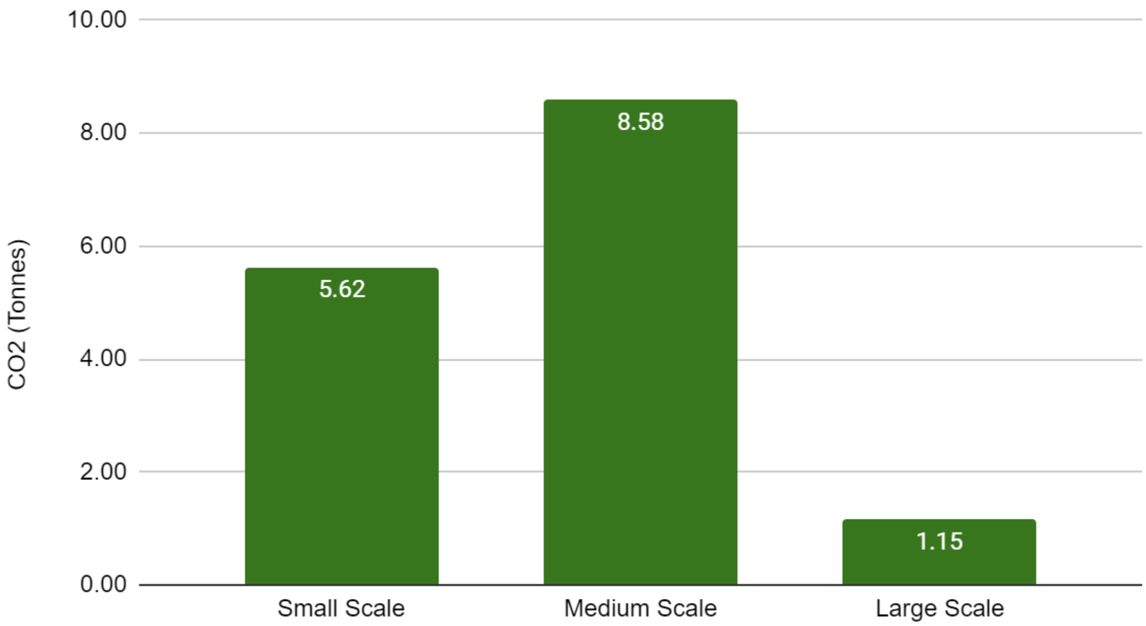


Figure 29: Net CO2e Sequestered per Tonne of Green Waste at Three Scales

The medium and large scales could be increased in efficiency even further by working with nearby farms to recycle the water used to quench the produced biochar, reducing the CO2e impact of the water to nearly zero. Additionally, the heat produced at the medium and large scales could be used for a variety of purposes, such as energy production, drying incoming feedstocks, or coupling with nearby industry such as canning or smelting, which would also reduce the impact of that heat that is leaving the system. The small scale doesn't have many options for heat recycling, but the water can also be recycled from that system. Overall, each system would yield a positive net impact for the environment, but the larger the scale, the larger that positive impact would be.

Life Cycle Costing Results

Life Cycle Assessment is a powerful tool for analysing the overall environmental effects of a system, but this type of analysis does not account for the monetary aspect of production. Life Cycle Costing (LCC) examines all of the input and output prices of the system. All of the input and output costs for the small, medium, and large scales are seen in Table 10. We based our analysis on these assumptions, regardless of scale: the pyrolyzer requires replacement every 15 years, and the cost of water is $2.34 per kL. The medium and large scales both involve a production plant and transportation. We assumed the cost of transporting raw materials and the end product was $1.22 per kilometer given maintenance and gas, and $0.87 per kilometer for the wages of the truck driver resulting in a total cost/km of $2.09. We assumed each council would have 5 collection trucks with each truck needing to be replaced every 15 years. The last assumption that needed to be made for the medium and large scales was the installation cost of the plant. This was based on a general comparison of similar existing plant sizes that would need to be purchased.

Table 10: Life Cycle Costing Results

Small Scale	**Input and Output costs**		**Medium Scale**	**Input and Output costs**		**Large Scale**	**Input and Output costs**
Pyrolyzer	$6,400.00		Pyrolyzer	$100,000		Pyrolyzer/ Plant	$700,000
			Plant Wages	$3,000,000		Plant Wages / Upkeep	$15,000,000
Water	$35.10		Water	$40,243		Water	$263,931
Total cost:	$6,435.10		Transportation	$6,285,820		Transporta tion	$392,209,611
			Trucking Wages	$3,765,253		Trucking Wages	$265,123,075
Costs			**Total**	$13,191,316		Total cost:	$673,296,617
Revenue	n/a		Biochar	$1,952,260		Biochar	$63,387,448
	n/a		Wood vinegar	$206,370,000		Wood Vinegar	$9,023,280,000
	n/a		**Total**	$208,322,260		**Total**	$9,086,667,448
	n/a		30 year net profit	$195,130,944		30 year net profit	$8,413,370,831

We started with the pyrolyzer when we computed the amount of input costs for the small scale. The Kon Tiki Kiln costs about $3,200 AUD and will be replaced every 15 years as stated above, bringing the total cost to $6,400 per household. When computing the cost of the water we took the total amount of water needed in kilograms and converted it to kilolitres, then multiplied it by the cost of water per kL. The small scale generated no revenue because all of the biochar produced will be used on the homeowners property and not sold. There is value added by the increased garden yields and water retention of the soil, but these benefits are very hard to estimate based on the variety in plant species and application by different households, so we didn't quantify them for this analysis.

Analysing the medium scale starts with the cost of the pyrolyzer and the plant. The portable pyrolyzer we looked at did not have a published cost but we were able to scale the cost of the large scale pyrolyzer based on the capacity (*Tire Pyrolysis Plant Cost Analysis | Fair Price - Beston*, 2020) . This brought the cost of the pyrolyzer to about $50,000, taking into account replacement after 15 years. The lifetime cost over 30 years would be roughly $100,000. When accounting for the wages of the people running the pyrolyzer, we estimated that two people running it would earn $50,000 each per year for a total cost of $3,000,000 over the lifetime of the plant. This estimate does not account for raises, training, or any other personnel related costs. Calculating the cost of the water was the same process as the small scale. We estimated that the medium scale would use 17,198 tonnes of water over the 30 years which totals to a cost of $40,203. The biggest expense for both the medium and large scale comes from the transportation and this was broken up into two sections; transportation costs and truck wages. There were 4,332,640 km traveled over the 30 year period and both of the wages and mileage numbers were based on kilometers traveled. We were able to multiply the total distance traveled by the $2.09 we calculated above to get the aggregate cost for transportation. We also considered the cost of replacing the collection truck every 15 years. At $200,000 per truck and with five trucks at each council, the total cost for trucks and transportation over 30 years would be $10,051,073. We didn't measure the economic benefit of the jobs created by building this plant, but that could be quantified in a more detailed study.

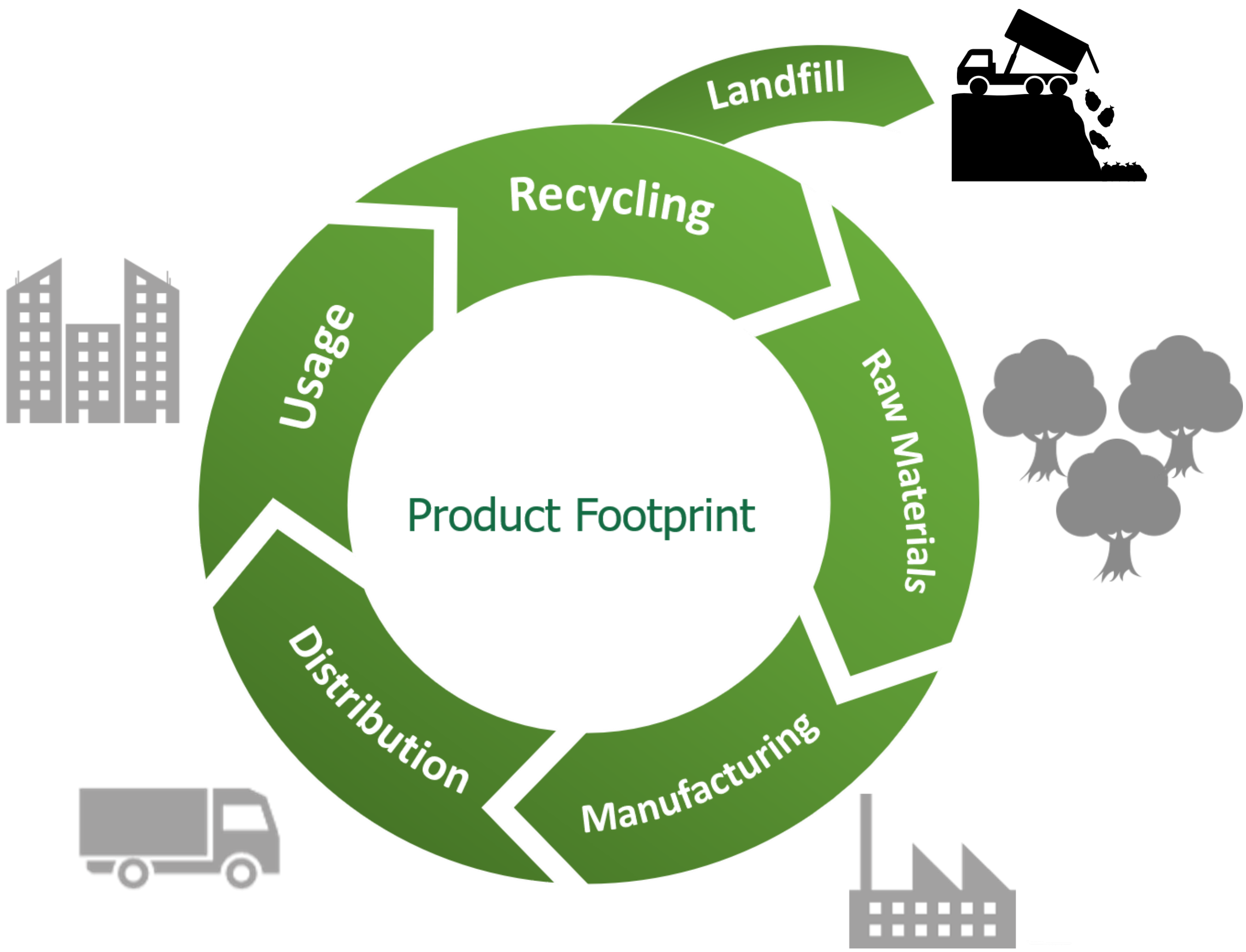
Medium scale costs are large, but the byproducts create a large return on investment. The price of biochar we estimated for the medium scale is $56.76 per ton, so the profit from biochar will be $1,952,260. The price for wood vinegar ranges from $2-$12 per litre depending on the quality of the feedstock processed; for the medium scale we estimated $6 per litre from average quality feedstock. Despite the name, wood vinegar can result from pyrolysis of many feedstocks. This will bring in the biggest earnings of $206,370,000 bringing the 30 year net profit to $195,130,944.

The analysis of the large scale is very similar to the analysis of the medium scale, starting with the cost of the plant and the pyrolyzer. We assumed a 25,000 square foot plant at $20 per square foot (Conrad Mackie, 2020) for an estimated total of $500,000. Calculating the cost of the pyrolyzer, we found reports stating that the price can vary from $60,000-$120,000 (*Tire Pyrolysis Plant Cost Analysis | Fair Price - Beston*, 2020). When calculating the cost of the labour from operating the plant over 30 years, we used the estimation of $75,000 per year and 5 workers. We assumed that the larger plant would be more complex, thus demanding a higher wage for increased difficulty of work than the medium scale. This equated to $11,250,000 for wages being paid over 30 years. To account for maintenance and utilities of the plant over the 30 years, we estimated an average of $125,000 per year, equating to $3,750,000 for maintenance and utilities. This brings the total cost of operating the plant for 30 years to $15,000,000. The large scale used 112,791 tonnes of water over the 30 years, which brings the total cost to $263,931. Calculating the costs of the transportation for the large scale follows the same process as the medium scale. Over 30 years, the trucks will travel 305,089,845km. We also considered the upfront cost of the collection trucks, and assumed that they had to be replaced every 15 years. This cost ended up being $200,000 per truck, and with 50 trucks across all ten councils, the total cost of transportation over 30 years would be $657,332,686.

The large scale has a high upfront cost, but the return on investment from the biochar and wood vinegar will surpass this cost over time. The price of biochar per ton for the large scale is $85.15. This is higher than the price for the medium scale due to the higher quality of the biochar. Since there will be 744,421 tonnes of biochar produced, the net profit from the biochar will be $63,387,448. Wood vinegar will make the most money at the large scale as well, and would be priced at approximately $8 per litre.

There will be 902,328,000 litres of wood vinegar being made at the large scale which would theoretically result in a profit of $9,023,280,000 from the wood vinegar. However, the global market for wood vinegar is currently valued at $1.8 billion AUD, so the likelihood of selling that quantity of wood vinegar is highly unlikely. The wood vinegar could also be added back into the biochar to increase its value and quality. Summing up all of these values for the large scale we get the maximum potential aggregate profit made from the large scale will be $8,413,370,831. A more in depth economic report of this will be necessary to properly scale and price these products, but our estimates show promising economic potential for this system.

We have analysed and summarised the potential positive environmental and economic effects that establishing a biochar production plant could have through our LCA and LCC procedures. Our final conclusions and recommendations follow.



Chapter 4: Recommendations

In our analysis of the application of biochar projects on different scales it was not our intention to pick one system over another, but to lay out the environmental benefits as well as the costs and potential income at each level. We present individual recommendations for each scale below.

Small Scale

Our survey responses and interview with Kerry Bowen suggested that having residents collect biowaste and processing it requires a commitment that many people may not be willing to make. Only some people were excited about making the effort to produce biochar on their own and very few were already involved in making or using it. This is why our first recommendation is **to identify a target audience.** Whether it is through social media groups or surveys, it is very important to find people who are interested in gardening and climate solution efforts. Our survey showed a lack of knowledge on biochar. First, there were several responses from the open ended section of the survey that asked for clarity on various basics of biochar production and use. We also received only 82 responses out of the much larger population of people it was available to, which may suggest that those who didn't fill it may have been even less interested or knowledgeable on the subject. This is where our recommendation to **establish a biochar education system** comes into play. A simple pamphlet, website, or demonstration for those that don't know about biochar and its uses could be an effective educational and marketing tool. Even though we didn't receive a large amount of survey responses, out of those that did respond, the majority were interested in hearing the results of our study, which suggests that there is a potential target audience.

The LCA indicated a net positive CO2e through sequestration at this and all scales. Naturally, this scale has the lowest sequestration per tonne, but it still has a significant impact. Kerry Bowen, being an owner of a Kon Tiki Kiln, mentioned that his biochar production was very infrequent. He only ran the machine a few times per year, and he indicated the amount of biochar produced from one cycle would be enough to meet his gardening needs for a few months.

This, combined with our LCC result that it would cost the owner approximately $6,450 over the 30 year period led us to our next recommendation: **sharing a machine between neighboring households.** This would significantly reduce the impact of manufacturing so many individual pyrolizers, and would allow for cost sharing and more efficient use of the technology. A downside to this might be having to plan out a schedule between neighbors. An alternative way to offset the initial costs would be for the owner of the machine to sell biochar locally to their neighbors or perhaps at a farmer's market.

Medium Scale

Those who answered our survey responded positively overall to the medium scale option, and our interviewees saw potential in this option as well. Similarly to the small scale, we recommend **establishing biochar education** to inform residents and other potential biochar customers of the benefits and uses of biochar in gardening, farming, and other applications. Some residents felt that donating their own biowaste, and then also having to pay a fee for the biochar produced from their own donated material was not fair. To address these concerns, we recommend a **deeper economic analysis** to properly price the biochar and also publish the results of this study for interested residents. Our interview with Maitland City Council Waste Management suggested the feasibility of the green bin waste disposal system, and survey respondents seemed more amenable to this than to transporting their waste to a location themselves. Based on this, we recommend **using green bins to collect green waste**. We also gathered data suggesting that more rural, less densely populated councils would incur higher transportation costs compared to more urban areas. Whether this would reduce the net positive impact of biochar production would depend on the amount of green waste collected in rural homes. Thus, we recommend a **detailed assessment of green waste production and distances traveled** for each council. Given the timeframe of our project, we were unable to obtain more specific data for each council.

Our LCA estimated the CO2e sequestration of the medium scale biochar project located in Maitland City Council to have a net positive effect. This means that despite the negative effects of transportation, heat output from processing, and water usage, the biochar produced will draw down enough carbon to compensate for these impacts. Our estimates from the analysis confirm what is probably common sense; this solution is more environmentally effective than the small scale, but less so than the large scale. To net even more benefits, we also recommend **recycling heat and water** from the plant to negate these impacts and even provide positive benefits in other areas.

Our LCC indicates that, based on our assumed biochar pricing, the medium scale will yield a net profit by the end of the 30 year mark, even if it takes a few years to earn back the up front cost of the building and installing the technology. This profit would be affected by biochar pricing and wages of the workers, which is an additional reason for our recommendation of an economic analysis, one that might also consider the economic impact of using biochar or its byproducts for energy supply or for other uses like improving local soil qualities and increasing harvests. This profit also doesn't account for the benefits of biochar use across the council.

Large Scale

The large scale project was a favoured option among several stakeholders and survey respondents. Some stakeholders believed that the potential economic and environmental benefits would be best seen at a large scale. Others believed that even though the profits would be greater, the heavy transportation would be counter-productive for the environment. This leads to our first recommendation for the large scale: **consider implementing 2-3 pyrolysis plants to reduce travel distances.** Our study didn't include calculations on where the best locations would be, but having them closer to more councils would be very beneficial. We were given this recommendation by several of our interviewees, as they believed that transportation distances could be too extensive. This leads us to our next recommendation: **only include councils with the best green waste per distance travelled for collection.** Since there are councils with large areas and low population densities, collection in these places could prove to be inefficient. Our LCA estimates show that collection within each council might have the most strain on the environment.

Collecting waste within a single council involves long travel distances, so eliminating the less efficient councils could prove to be better. There are several other points to consider at the large scale. As previously stated, biochar has a significant heat output. A recommendation that we have is to **locate the plant(s) near industries that can utilise the heat.** This will reduce both emissions and cost. Heat could be either used for electricity production for industrial processes such as canning, metal processing, or others. This is something that requires further exploration but some interviewees suggested potential in those areas. Similar to the medium scale, water can also be recycled. One last recommendation is to **consider all sources of biomass**. We only considered green waste from residences, but vineyards and forestry/timber businesses could be a potential source of feedstock and could also be potential biochar consumers.

In summary, biochar systems at each of these scales have the potential to reduce greenhouse gas emissions and generate a profit, but each involves different stakeholders who must be persuaded and educated and different kinds of research to provide evidence. In order to summarise our final recommendations from this chapter, we compiled them in Table 11.

Table 11: Summary of Recommendation

Scale	Recommendation
Small	Identify a specific target market for small scale biochar
	Create biochar education programs and/or materials
	Share biochar machines between households, possibly a street or neighborhood system
Medium	Conduct a deeper economic analysis
	Employ green bins for garden waste collection
	Assess green waste production and distances traveled for each council
	Recycle heat and water from the pyrolization process
Large	Consider multiple regional pyrolysis plants to reduce travel distances
	Consider which councils have the best amount of green waste to distance ratio
	Locate the pyrolysis plant(s) near industries that can utilise the heat or use heat to preprocess feedstock
	Consider additional sources of biomass, such as timber or vineyards that could contract waste or consider them as potential buyers

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Meet the Authors

Jack's Biography

My name is Jack Waterman, and I'm a Mechanical Engineering major in my third year of university. I was born in Middlebury, Vermont, and have lived there my entire life. I have always had a love for the outdoors and the environment, and have participated in multiple courses and projects based around reducing environmental impact, so this project was a very meaningful extension of that for me. I have also gone to and now work at a summer camp that heavily relies on the outdoors, so any efforts to preserve nature such as this project are very meaningful to me. I have had a lifelong dream of travelling to Australia, so missing out on this opportunity due to COVID-19 was rather disappointing, but I hope to have the opportunity in the future.

Ricardo's Biography

My name is Ricardo Ferrua. I am best known as "Ricky". I was born and raised in Santo Domingo, in the Dominican Republic. For as long as I can remember, I have had a deep passion with cars. My birthday and Christmas gifts usually involved car-related stuff, from Hot Wheels to car racing video games. This has played a big part in choosing Mechanical Engineering as my mayor. The past few years I have done several internships related to engineering, but surprisingly the job in which I learned the most was as a camp counselor. It was the opening year, which meant that everything was disorganized. I learned to work under pressure, as we constantly had to improvise to solve last minute issues. It was a month full of stress and hard work, which gave me a glimpse of how things can get in the real world. I wish we had the opportunity to visit Australia, but it will have to be another day. I really hope this project has a positive effect on the community and the environment!

Meet the Authors

John's Biography

Hello, my name is John Pattinson. I am a junior at Worcester Polytechnic Institute studying mechanical engineering. I was born and raised in Seattle, Washington. I followed the path of my sister, Ellen, and chose to move to the east coast of the United States for my studies. As I am from the Pacific Northwest I basically grew up outside. I love being outdoors and this project has really allowed me to have a real impact on the environment. I would have loved to travel to Melbourne for IQP, sadly this could not happen. I hope that in the future I will still be able to travel to Australia and see the positive impact this project is having.

Zack's Biography

My name is Zachary Chapins and I am a Mechanical Robotics double major in the junior year of my studies. I was born and raised in Westchester, New York. I have always had a knack for engineering, and I have been working with my father at his CNC machine shop ever since I was a kid. It has always challenged my mind in different ways sparking different interests leading me to choose engineering as my choice of study. I am very interested in many outdoor activities which lead me to have a real interest in this project because I care about the environment. During this project I was able to further develop many project skills during the 2-month period of this project ranging from completing large tasks in a short period of time, to learning and understanding how to complete complex assessments like an LCA or LCC. Completing this project online had its struggles but, in the end it was a great experience. Being able to go to Melbourne would have made the experience much better but I hope to travel to Australia once I graduate.

Specific authorship credits can be found in Section F of the Supplemental Materials