Biochar Market Profile Report

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Table of Contents

1. Executive Summary

This report analyzes the emerging biochar market in Australia in order to assess how biochar can be a stimulant to develop a biohub in Gippsland. Biochar is a charcoal-like substance that is made from biomass feedstocks, such as forestry residues, that can be used in various applications to numerous beneficial ends. One of its well-known benefits is its ability to sequester carbon, thus lowering carbon emissions. Biochar can be made through a process called pyrolysis. Pyrolysis decomposes organic materials at high temperatures in the absence of oxygen.

Research shows that the current biochar market in Australia is small and fragmented. One of the reasons for this is the divide between the early adopters of biochar, who see all the environmental and agronomic benefits, and the critics, who focus on the economic issues of further developing the biochar market. However, there is a strong community of the biochar producers, consumers, and technology producers, known as the Australian New Zealand Biochar Initiative (ANZBI), that are working to develop the biochar industry.

In the United States, the biochar market is also a new industry, but it is further developed than in Australia. There are currently around 135 biochar producers in the US, with most of those being located on the west coast. They produce approximately 45,000 tonnes of biochar per annum. Other biochar markets, such as Europe and China, are also further developed compared to Australia. One reason for this is because there is government support to use biochar, as there are laws rewarding those who do.

The potential for the biochar market in Australia is large. One potential market is using biochar as a fertilizer additive. Biochar has been found to help with soil fertility when mixed with fertilizer. However, too much biochar with fertilizer can be more harmful than helpful, so only a small amount can be used. Another potential market is adding biochar to concrete. Research shows that the addition of biochar can increase the 90-day strength of the concrete.

Based on the successful development of the biochar market in other countries and the potential for the industry in Australia, the following recommendations were made:

1. Establish an Australian biochar certification
2. Develop a detailed report of the current biochar production in Australia, similar to the Dovetail Report from the US
3. Assess Australia's biochar market scalability for projections into other markets
4. Map biochar potential in all foreseeable markets
5. Promote biochar's brand as a sustainable solution to increase consumer's knowledge
6. Expand into other value-added products from biochar for diversification

2. Introduction

Biochar is a highly porous substance primarily made up of carbon, nitrogen, hydrogen and oxygen. The amorphous compound is produced via pyrolysis, the heating of a material under high pressure in an environment free of oxygen. The feedstocks for generating biochar include all types of organic matter. This ranges from dry, clean, woody biomass, to moist, contaminated sewage sludges. Figure 1 depicts different types of biochar made from various kinds of biomass. Although biochar is similar in appearance to charcoal, and even shares many of the same applications, it has an important distinction. Unlike charcoal, the market for biochar is only in its embryonic stages and its future is uncertain.

Figure 1. Biochars from different sources, and by pyrolyzation at different temperatures (Mašek, Buss, & Sohi, 2018).

Biochar shows the potential for being a lucrative value-added product for waste streams in Australia. Research shows that it performs very well in a myriad of applications, from a soil amendment, to a concrete strengthening agent. It also does so in an environmentally responsible manner by sequestering carbon. Naturally, there is much scrutiny over this emerging product. There is very limited research and hard data available for the state of the market globally, but especially so in Australia. Altogether, this questions the worth, and viability, of further developing the biochar market in Australia. For instance critics of biochar cite the lack of hard data as a reason for limited development in the industry.

The purpose of this report is to profile the state of the biochar market globally for future researchers so this question can begin to be answered. Also, to allow a pathway to be creates for others to perform further investigations into areas where research is limited or nonexistent. Since the market is arguably most developed in the United States, this first section of this report will focus on the evolution of the industry there as well as Australia. The next sections focus on the current status of the market in Australia, and draw on the US and other international biochar markets to give insight on the prospects of a developed market in Australia. Finally, all of the amassed information culminate in recommendations for the direction of future research into the topic, as well as potential steps to be taken for the industry to grow in Australia.

3. Background

3.1 Biochar

Although biochar looks like common charcoal, it is produced using a process that minimises contaminants and is built upon a sustainability framework. Pyrolysis allows carbon from biomass sources to be "locked up" into biochar, making that carbon unable to return to the atmosphere. Biochar is roughly 70% carbon and is porous, providing extra surface area that can house microorganisms, protecting them from predation and drying while providing many of their carbon and mineral nutrient needs. Biochar's properties allow it to become a valuable tool to combat climate change.

Along with biochar, other value-added product streams come from its production. In terms of pyrolysis and biochar, the value-added products fall into two categories: value-added byproducts of biochar and value-added products of biochar. There are many known values of biochar itself. It can be processed further into activated carbon and carbon black, or as stated before, used as a strengthening amendment to cement. More applications can be found in Appendix A.

However, the biochar market is still in its infancy. It is relatively undeveloped, and there are things that are uncertain. Biochar is very similar to its carbon-based relatives, activated carbon and carbon black, and there is no universal standard set for biochar. Currently, there is no easy way to measure the quality of biochar or to compare biochar from different biomass sources. Solutions to these issues are being considered by organizations like the Australian New Zealand Biochar Initiative (ANZBI), the United States Biochar Initiative (USBI), and the International Biochar Initiative (IBI).

3.2 Processes

Two of the technologies that exist to process waste biomass into a profitable supply of biochar and syngas are gasification and pyrolysis. Both processes offer unique opportunities and should be chosen based on what the desired outcome is. For instance, because pyrolysis generally runs slower than gasification and thus produces more biochar, it is of great interest to producers who are primarily concerned with the market for value-added biochar products.

3.2.1 Pyrolysis

Pyrolysis, as stated before, is a process in which can produce biochar. The process takes the biomass into a pyrolysis unit where the biomass is heated to over 300 °C. In this chamber, there is a lack of oxygen, which allows the chamber to have no fire while heating. Thus, the biomass chemically reacts due to the high temperatures and results in the creation of a char substance. This char substance is the resulting carbon-based biochar. However, there are some byproducts, as stated before, in the form of bio-oil and syngas. Since there is no burning in the process of pyrolysis, there is very minimal carbon dioxide production. This can be seen in Figure 2, where the full process of pyrolysis is outlined.

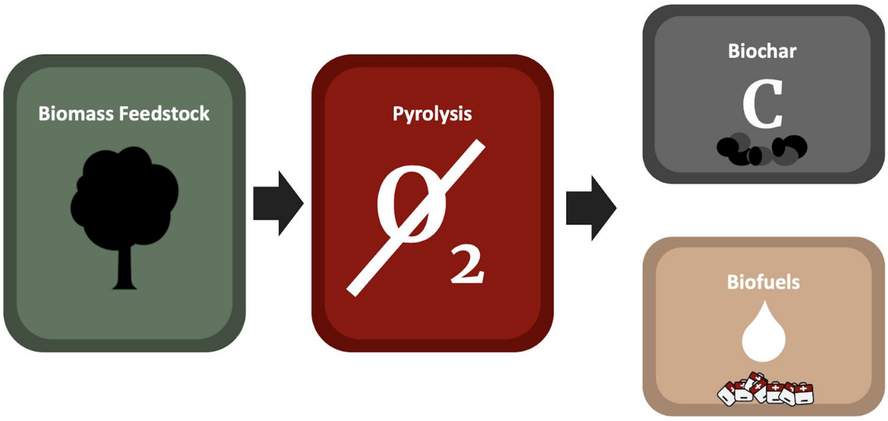

Figure 2. The Process of Pyrolysis

The amount of biochar produced depends on the temperature of which pyrolysis is run at. Higher temperatures yield a faster result, however, this approach tends to produce less biochar. In contrast, lower temperature operations generally yield more biochar. However it takes more time and produces fewer byproducts. Thus, the results are highly dependent on the method the pyrolysis unit uses to achieve pyrolysis.

4. Results

4.1 Biochar's Evolution in the US

4.1.1 Key Observations

Even in biochar's most developed markets, studies are limited. The United States Department of Agriculture (USDA) reports that 318 million cropland acres were planted in 2016 (2017). For every 1% carbon increase in the soil, it takes 9.4 tons of carbon per acre. Thus it would take approximately 3 billion tonnes of biochar to enhance US cropland in its entirety (Dovetail, 2018). Despite this vast potential for the use of biochar, the US produces an estimated 45,000 tons annually (Dovetail, 2018). An earlier estimate of industry production performed by the USBI found that between 15,000 and 20,000 tons were produced each year (United States Biochar Initiative, 2019). Despite its apparently small size, the US biochar industry still dwarfs Australia's. As such, commonalities between the markets will be imperative to understanding and predicting the growth of the market in Australia.

4.1.2 Scale and Application

The limited survey by Dovetail Partners represents one of the most in-depth studies into the state of the US biochar industry. As stated, it estimates that 45,000 tons of char are produced per annum. To create this mass of biochar, it requires 200,000 tons of dry biomass. Since most feedstocks are between 20% and 60% moist, between 125,000 and 250,000 tons of wet, raw biomass must be harvested to create the totality of biochar each year in the U.S.. To contextualise these tonnages, the US generated over 70 million tons of solid wood waste in 2010 (Falk and McKeever, 2012). Moreover, there is a large amount of biomass that is available for conversion into biochar.

According to the USBI, there are approximately 135 biochar producers in the US. The survey received 45% response rate, which is low, but the responders cover a wide section of the market. The results show that the market is fragmented, as demonstrated in Figure 3. Two-thirds of all respondents are small producers, making less than 50 tonnes of biochar annually.

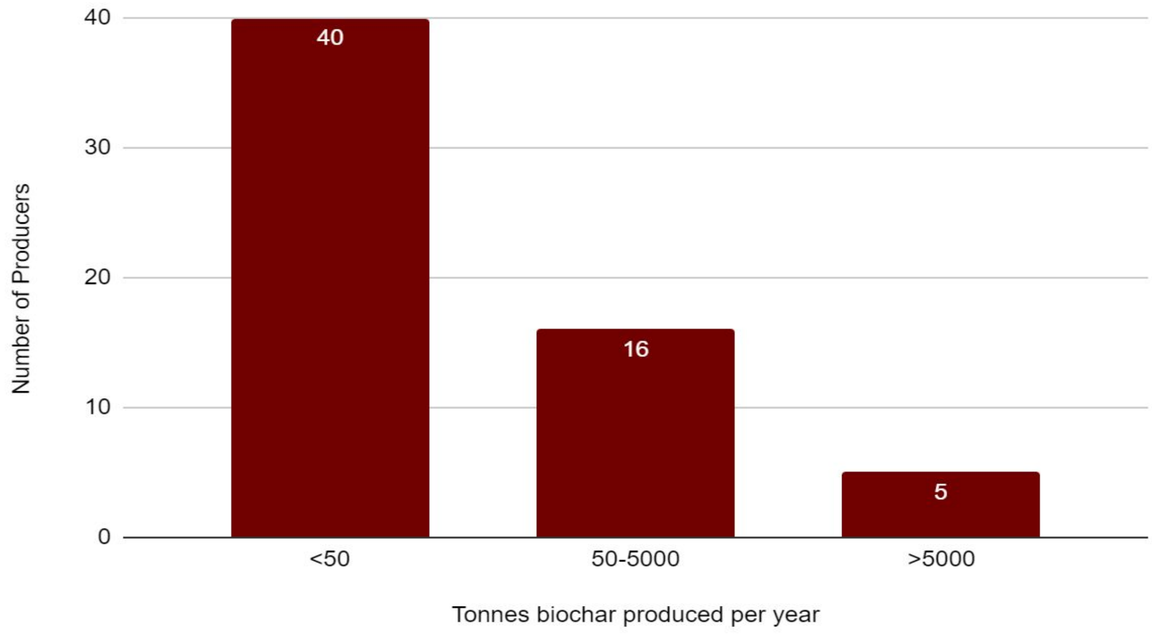

Figure 3. Distribution of North American producer production (Adapted from Dovetail, 2018).

Sixty seven percent of producers make less than 500 tons per annum. The market is clearly defined by the great number of small scale producers and relatively few large manufacturers. These producers are also widespread across a large geographical area, in addition to being mostly small scale. The survey covered all of North America, and while there are areas that contain multiple producers, overall production is spread out across the continent. Figure 4 illustrates this.

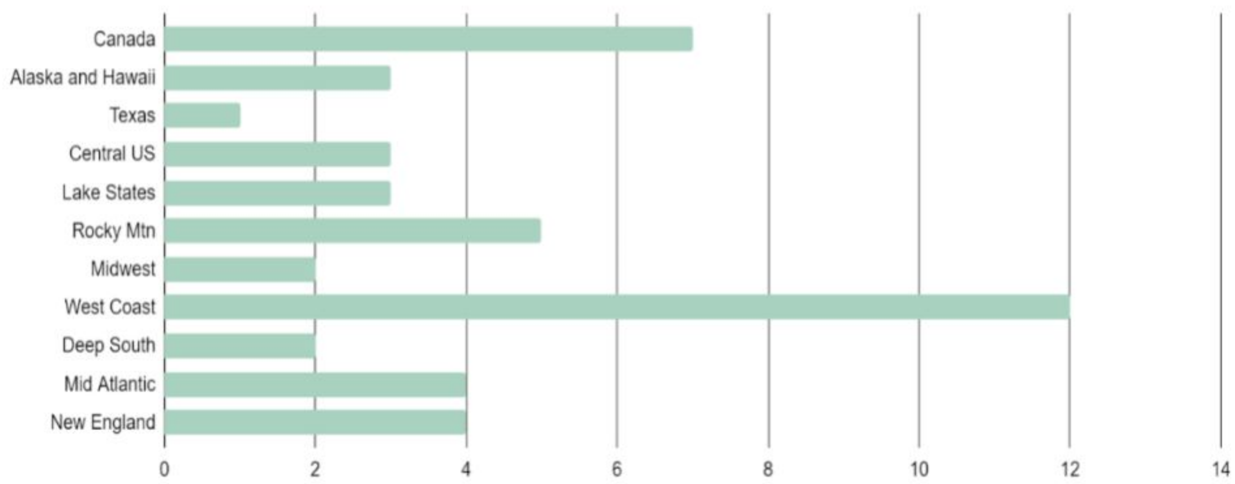

Figure 4. Geographic distribution of North American producers (Adapted from Dovetail, 2018).

Production is clearly clustered in the West Coast region, particularly in California. The most prevalent kind of biomass in this region is woody waste, which is similar to that in Gippsland, AU.

Since there are a number of other valuable products created during pyrolysis, not all producers may process biomass with the intent of making biochar. They could produce energy in the form of heat, gaseous fuel, or electricity, or simply want a way to dispose of their waste. Figure 5 shows the production priorities of the respondents.

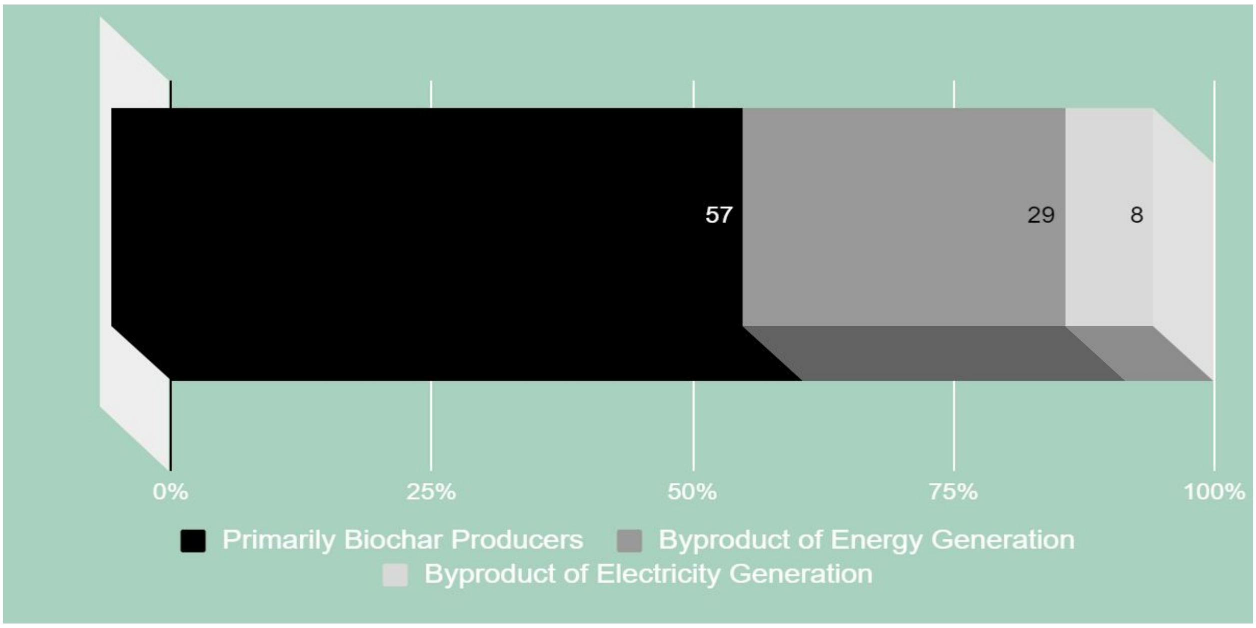

Figure 5. Biochar production outputs (Adapted from Dovetail, 2018).

4.1.3 Pricing

In January 2019, Hoffman-Krull (2019) conducted a biochar market analysis for the San Juan County in California. The main goal was to determine if, and how, the biochar market was growing in San Juan County, as well as to determine its potential market expansion. This assessment was completed by conducting interviews with various individuals, such as farmers, gardeners, and biochar businesses (Hoffman-Krull, 2019). The prices found through this study shed light on the rest of the United States market and are shown in Table 1.

Table 1. Price of biochar of four businesses near San Juan County.

Business	Feedstock Used	Price per cubic yard	Other Options
Olympic Biochar	Forestry Residues	$135 (tote bag) $105 (bulk)	
Pacific Biochar	Forestry Residues	$68 (loose) $88 (bulk tote bag)	$244 (bulk tote bag, 3 cubic yards) $13 (retail bag, 1.5 cubic

			feet)
Pacific Biochar	Worm Castings & Rice Bran	$89 (loose) $163 (bulk tote bag)	$17.50 (retail bag, 1.5 cubic feet)
Oregon Biochar Solutions	Forestry Residues	$135 (loose) $249.50 (bulk tote bag) $150 (bagged truckload of 50 tote bags)	
Biochar Supreme	Forestry Residues	$350 (bulk tote bag)	$39 (cubic foot bag)

4.1.4 Research and Development

In the past two decades, research on biochar has been lead by the various universities in the US. The popularity of biochar has grown as it is a candidate that can amend the soil. As the number of research papers that looked into biochar grew the more uses for it were discovered. Uses such as filtration have become the most common in the US. This is due to all of the funding that has been put into this specific application of biochar. In the US market filtration as a use for biochar has the second highest expectation for growth (Dovetail, 2018). This is different compared to most other countries where the emphasis has been in agriculture. Water filtration using biochar has the potential to grow with the intervention of further research.

Biochar is said to be less activated than activated carbon (Nigel Murphy, personal conversation, 2019). However it shows potential to be further developed. This is where private industry can pick up from where the research institutions have left off. There is a big need to fund the development of biochar into tangible products that can be used to further. For the industry to progress there needs to be steps taken to secure funding for development. The current system of university driven research can only go so far. More development into biochar could lead to more efficient production and could improve the market viability of the product. All of this investment should also be done with the assistance of government. Industry needs to work with government in order to further develop biochar.

4.1.5 Government Policy and Legislation

Regulatory bodies can create legislation that can greatly influence biochar in the market. Strict rules on production and feedstocks can throttle growth, while tax credits and government funding can propel biochar into the forefront of the market. James Joyce discussed this in more detail. He purports that The USBI highlights some key pieces of legislation affecting biochar's market development.

The "WECHAR" Bill was put before Congress in 2009 and was formally titled the "Water Efficiency via Carbon Harvesting and Restoration Act." The bill proposed a guaranteed program for biochar R&D, programs for landscape restoration using biochar, as well as setting up a grant system to garner research funding (USBI, 2019). The bill is yet to be passed, but represents a leap forward for biochar. Investment into R&D, as well as real applications, would offer a wealth of knowledge into the utilisation of biochar and bring biochar further into the public eye.

The Clean Energy Partnerships Act deals with any cap-and-trade bills implemented in the US. The goal of the bill is to maximise the financial incentives for the agricultural and forestry sectors of the US to reduce GHG emissions. The bill aims to keep these incentives high, such that the cap-and-trade programs do not come at the cost of consumers. Biochar production is specifically identified in this act as a form of carbon sequestration eligible for the offset credits. It also highlights the necessity for R&D into biochar and authorises funding towards it. Like the "WECHAR" bill, it was tabled in 2009, but was never enacted (USBI, 2019).

One instance where a bill successfully implemented a credit system where biochar is eligible is in California. The California Global Warming Solutions Act of 2006 offers credits to businesses that avoid emissions of a number of GHGs. The eligible GHGs are:

1. Carbon dioxide (CO2)
2. Methane (CH4)
3. Nitrous oxide (N2O)
4. Hydrofluorocarbons (HFCs)
5. Perfluorocarbons (PFCs)
6. Sulfur hexafluoride (SF6)
7. Nitrogen trifluoride* (NF3)

Businesses that produce GHGs must purchase 'permits,' the offset credits, allowing them to pollute. Each permit gives an allowance by ton of GHG. These businesses can purchase the credits from businesses that earn them by offsetting their own emissions, which allows the polluting companies to do so. Over time, the plan is to reduce the total number of allowances available, and in doing so, decrease the net emissions. The money collected from the state through the program goes towards funding programs intended to reduce GHG emissions. The regulatory bodies also allow for carbon offsets to be purchased in replacement of allowances for up to 8% of a business's total emissions (Smith, 2018).

A similar federal level carbon offset program is called the 45Q Tax Credit. The system handles any sort of carbon dioxide capture, and tax returns vary on the end use of the CO_2. One of the two categories of use is secure geologic storage in oil fields through enhanced oil refinery (EOR) or saline aquifers. The other category is 'beneficial' uses of CO_2, such as fuel and chemical production or as a concrete amendment. The federal government defines these 'beneficial' uses as any implementation that reduces emissions. Only certain parties are eligible. There are annual carbon capture thresholds. Projects that fall under the discussed 'beneficial' uses, besides EOR, must capture between 25,000 and 500,000 metric tons of CO_2 to be eligible, varying by end uses. For industrial facilities excluding electricity generating units, over 100,000 metric tons must be captured. Lastly, 500,000 metric tons of CO_2 must be captured for electricity generating units (Christensen, 2018). As of 2018, there are different values for the tax credits depending on the end-use of the CO_2, with credits increasing over a 10 year period. 2018 values are shown in Figure 6.

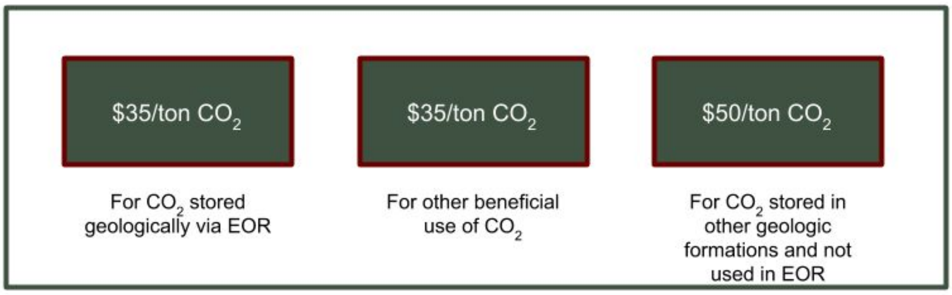

Figure 6. 45Q Tax Credit amounts based on project type (Adapted from Christensen, 2018)

4.2 Biochar's Evolution in Australia

4.2.1 Key Observations

In Australia, the biochar market is still in its early stages. Supporters and early adopters of biochar recognise the benefits, including increased crop yield, soil remediation, reduced greenhouse gas emissions, and carbon sequestration. However, critics point out the economic issues with developing the biochar market, along with the disconnect between the concept of biochar in published work and the real-life applications of biochar. This division has lead to the current biochar market in Australia being small and fragmented. Nonetheless, those that are using biochar in a number of different applications have found multiple benefits agronomically, environmentally, and socially.

4.2.2 Scale and Application

In 2018, it was found that Australia produced less than 50,000 tonnes of biochar per year (Joseph & Pan, 2018). Between February and March of 2019, 17 biochar users in Australia were surveyed. The amount of biochar that is either acquired by these users, or self-made, ranges from 2.5 kg to 25 tonnes per acquisition, with the average being 7.6 tonnes (Robb & Joseph, 2019). Of the users who purchased their biochar, they usually bought enough to last them a year, which meant they purchased larger quantities. On the other hand, users who produced their own biochar typically made it in smaller quantities.

In terms of the number of people in the biochar industry, there are over 85 members in the Australia New Zealand Biochar Initiative (ANZBI). These members include growers, biochar producers, scientists, technology producers, and other stakeholders (ANZBI, n.d.). Through the ANZBI, these members are working towards further developing the biochar market in Australia through research, case studies, and holding annual conferences.

It was found that 16% of consumers use biochar as a feed additive, with soil rehabilitation and crop yield effect following with 13% (Robb & Joseph, 2019). A breakdown of all biochar uses in practice is shown in Figure 7.

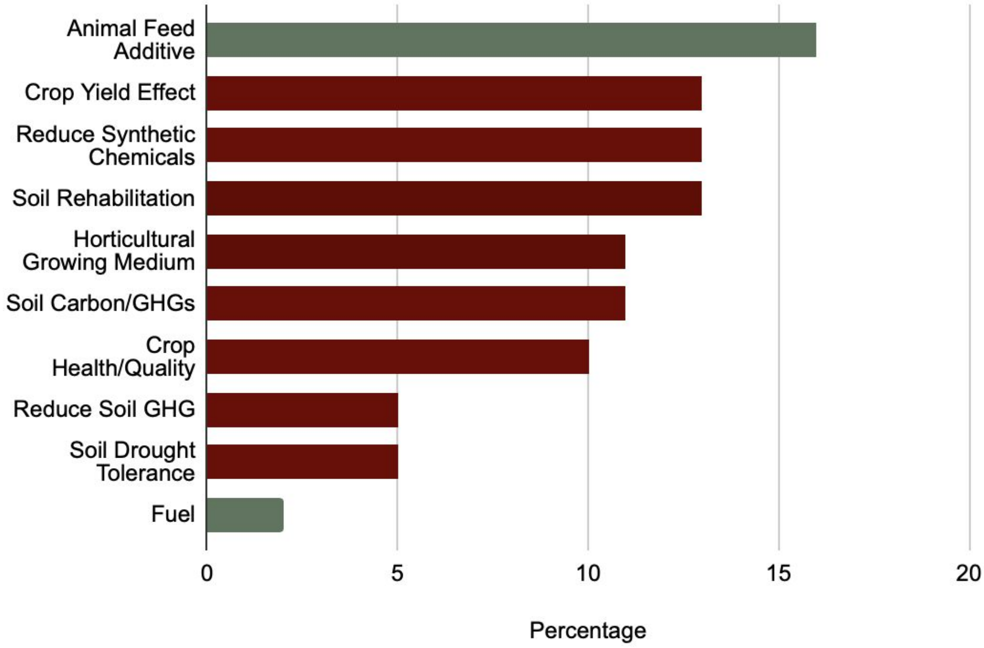

Figure 7. Different uses of biochar in Australia (Adapted from Robb & Joseph, 2019).

Using biochar as a feed additive requires the use of biochar daily. Because of this, the amount of biochar needed annually is high, ranging from 0.2 to 18.75 metric tonnes (Robb & Joseph, 2019). Farmers surveyed that feed biochar to livestock said that all the biochars were made from woody waste, and they were purchased from a biochar producer. The range of distances that the biochar was transported was from 20 km to 3000 km, with the average being 876 km (Robb & Joseph, 2019). These biochars are usually crushed to 2-4 mm particles, with the char only representing 0.3-3% of the feed mixtures. Adding biochar as a feed additive resulted in cows producing milk earlier than expected and increased farms' profitability by around $4,000 AUD per year (Robb & Joseph, 2019). Some of the other benefits biochar users found include improved overall health of cattle, improved calf development due to fuller udders on beef cattle, and no need to apply fertilizer to pasture in 2 years due to biochar infused manure.

Out of the 17 biochar users surveyed, 11 of them were growers, with most producing vegetables and fruit trees (Robb & Joseph, 2019). The need for these growers to use biochar more frequently is less than those using biochar as a feed additive. The amount of times growers apply biochar varies greatly, depending on the scale. For small scale growers, the use of biochar is more frequent, with some using it weekly, some using it monthly, and some only once a year. On the other hand, large scale growers only applied biochar once before planting. Unlike those using biochar as a feed additive, growers were more likely to make their own biochar, which was produced using mostly woody waste, but with some using straw and green waste. Those who produced biochar produced a small amount of biochar, usually under 200 liters (Robb & Joseph, 2019). However, there was one producer who produced around 11 tonnes in a year. The 3 producers that purchased biochar bought more of it than the amount produced by the other growers. This ranged from 2.4 to 25 metric tonnes per acquisition (Robb & Joseph, 2019). The distance this biochar was transported ranged from 20 to 3000 km, thus adding to the cost of the biochar due to shipping. There were several different ways the growers applied the biochar:

- Using a spreader before adding into planting beds
- Applying it 100 mm below the soil
- Applying it 300-600 mm below the soil
- Applying it in the planting hole before actually planting

There were various benefits found with using biochar as a soil amendment. Some of the benefits these growers experienced include improved soil friability, improved soil moisture retention, improved plant growth, and reduce odors from manures.

4.2.3 Pricing

Out of 17 biochar users surveyed, 8 of them make their own biochar. Of the 7 users who buy their biochar, the price per tonne ranged from $100 AUD to $6,750 AUD, with the average being $1,807 AUD (Robb & Joseph, 2019). In the case of the lowest-priced biochar, SIMCOA silicon smelter had sourced it (*ibid*). This biochar is a byproduct of the smelting process allowing the seller to price the biochar at unrealistic prices.

The biggest producer of biochar currently in Australia is Green Man Char. They produce five different products: biochar, wood vinegar, horticultural char, ultra-fine biochar, and coarse biochar (Green Man Char, n.d.). All of these products are available in various amounts. Table 2 shows the different prices, along with their respective volumes and approximate weight, of Green Man Char’s regular biochar. For quantities of more than 1000 litres, a separate request must be written and emailed to Green Man Char.

Table 2. Green Man Char’s regular biochar prices.

Volumes	**Price (AUD)**	**Approximate Weight**
300 mL	$4.00	150 g
1 L	$10.00	0.5 kg

5 L	$15.00	2.5 kg
10 L	$20.00	5 kg
25 L	$50.00	13 kg
40 L	$60.00	20 kg
500 L	$550.00	250 kg
1000 L	$880.00	550 kg

4.2.4 Research and Development

In terms of research into biochar, there have been a number of case studies in Australia that focus on different applications of biochar, which have been documented in the 2019 ANZBI report. For example, a cucumber farm near Geraldton completed a biochar trial in 2016 with Energy Farmers Australia using poultry litter biochar (Robb & Joseph, 2019). They had six different treatments, with four having different amounts of biochar and fertilizer, and two just being biochar. During the harvesting season, cucumbers were picked and weighed. It was found that the best treatment was with a low rate of both biochar and fertilizer, as it produced the heaviest cucumbers and resulted in the most financial value, with $52 AUD per kg of biochar (Robb & Joseph, 2019). This treatment also happens to be the cheapest. More information about this case study, and others, can be found in Appendix B, and graphs showing data from case studies can be found in Appendix C.

Beyond the case studies found in the 2019 ANZBI report, there has been other research into biochar. Dr. Stephen Joseph has researching the effect of feeding biochar mineral complexes to animals. He specifically focused on the role of biofilms on the conversion of feed and production of methane, and how biochar affects this. Joseph found that the biochar that is absorbed by the biofilms causes biotic and abiotic reactions that reduces the production of methane and increases nutrient availability. The biochar also alters both the pH and Eh in the bulk of the rumen, which results in changes in the microbial communities and the decomposition of the feed. More information about Dr. Stephen Joseph's research, and other research, can be found in Appendix D.

4.3.5 Government Policy and Legislation

The Australian Emissions Reduction Fund grants businesses an opportunity to turn each tonne of carbon dioxide abated, or safely stored, into Australian carbon credit units (ACCU). The credits are available to any business that adopt new practices and technologies that avoid greenhouse gas emissions and improve energy efficiency. ACCUs can be sold for revenue. The eligibility criteria are summarised in Figure 8.

A Project Should:

- Be carried out in AU
- Be new, ie. not already started at the time of registry with the exceptions of:
  - Savanna fire management projects
  - Some projects regarding landfill gas methods
- Be legal to conduct

A Project Should Not:

- Not already required under law with some exceptions
- Not likely carried out for a different Commonwealth, state or territory program
- Rely on generated ACCUs to finance the start of the project
- Receive funding, rebates, or financial incentives from other govt programs

Figure 8. Eligibility requirements and exclusions for the Australian Emissions Reduction Fund (Clean Energy Regulator, 2018).

As of May 2019, ACCUs traded for around \$16.50/t, which is a 12 month high. These prices are about 20% greater than the volume-weighted average price put out by the Emissions Reduction Fund, or \$13.87/t. Figure 9 demonstrates the price fluctuations of ACCUs over the past year.

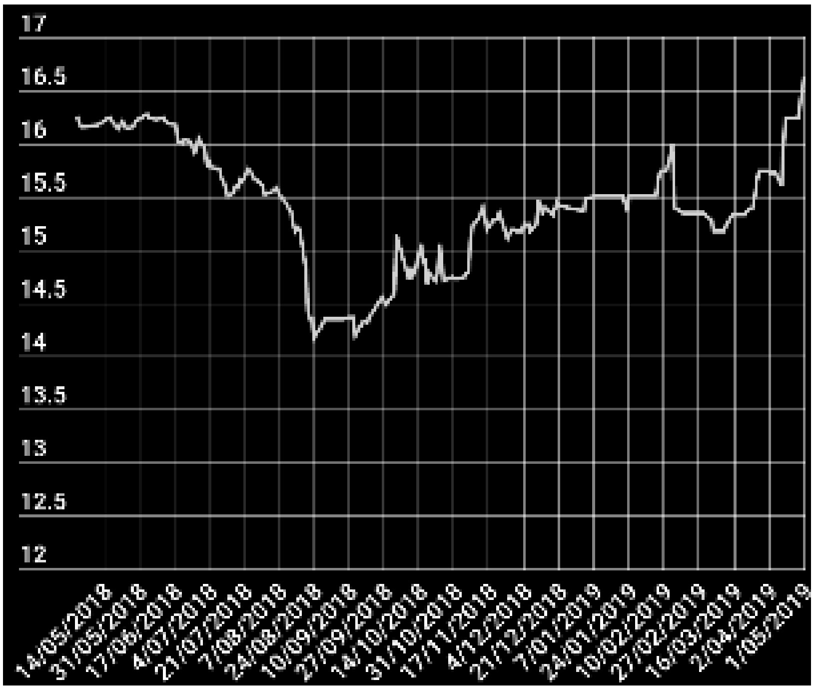

Figure 9. Daily ACCU (AUD) spot price (Adapted from RepuTex Connect, 2019).

As diverting waste biomass from incineration or landfill avoids greenhouse gas emissions, biochar production is eligible for the Emissions Reduction Fund. The revenue from the ACCUs provides an incentive for companies looking to dispose of waste biomass.

Large-scale generation certificates (LGCs) apply to electricity generated by producers using eligible renewable energy sources. LGCs are produced per megawatt hour (MWh) of eligible electricity created by a power station. The amount of eligible electricity a power station can claim LGCs for is summarised in Figure 10.

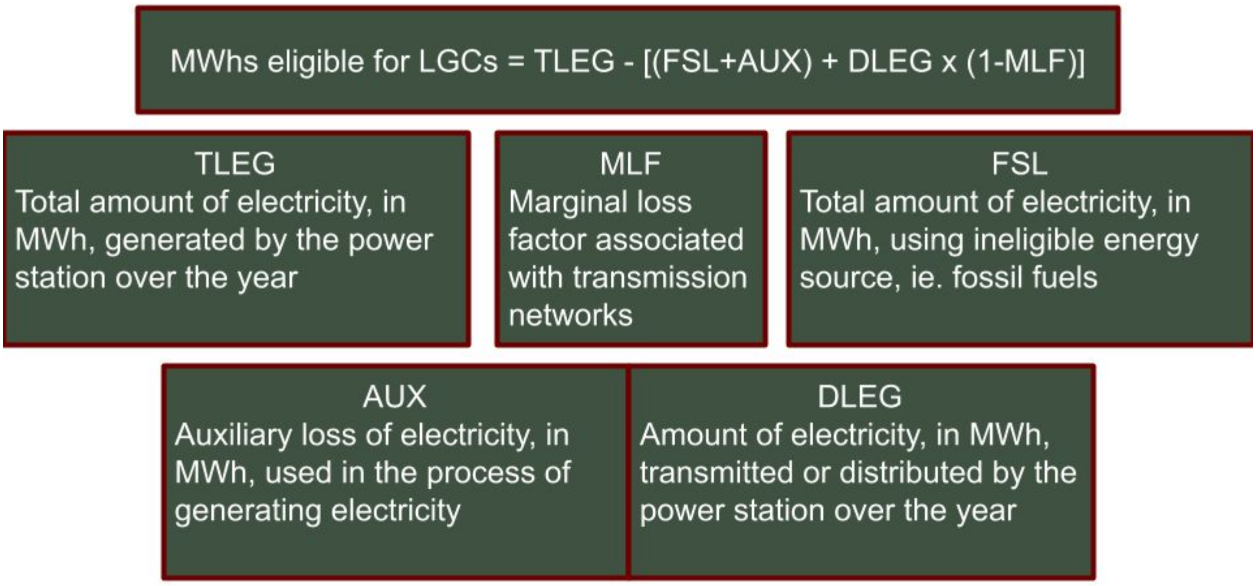

Figure 10. Formula for calculation of total MWhs of electricity eligible to claim LGCs for (Clean Energy Regulator, 2019).

The formula essentially says that is the total electricity that is produced by non-renewable sources, lost in powering auxiliary equipment to generate electricity in the first place, or lost during distribution leaves the total electricity created by renewable sources, and therefore can have LGCs claimed for (Clean Energy Regulator, 2019).

LGCs can be sold off between liable entities (usually electricity retailers). At the end of each year, liable entities surrender LGCs to the Clean Energy Regulator. LGCs can be traded for revenue between companies so that companies producing more than their obliged number of LGCs can sell them to other companies that cannot produce enough. Since the energy produced from pyrolysis is renewable, they would be eligible for these LGCs and make the production of biochar more profitable.

4.4 International Outlook

4.4.1 Europe

The biochar market in Europe is more developed than it is in Australia. Similar to Australia, Europe's main biomass feedstocks come from agriculture and forestry (Elbersen, Startisky, Naeff, Hengeveld & Schelhaas, 2010). Throughout Europe, the total biochar production is around 6,750 tonnes per year (Schmidt, n.d.). The breakdown of the top-producing European countries can be found in Table 3.

Table 3. Biochar production in Europe by country.

Country	**Biochar Produced (Tonnes)**
Germany	5,000
Switzerland	700
Austria	500
UK	500
All other European countries	50

One of the major differences between Australia and Europe's biochar markets is that Europe has a certification for its biochar. The European Biochar Certificate (EBC), which was established by the European Biochar Foundation in 2010, helps to provide sustainable biochar production and low hazard use in agronomic systems (EBC, n.d.). The EBC follows the IBI guidelines, along with addition regulations relating to on-site control of sustainable production. There are currently 12 EBC certified producers in Europe.

One of the biggest biochar markets in Europe is using biochar as a feed additive in livestock production. There have been many benefits found from feeding biochar to animals, and they can be organised into three different categories: agronomic, environmental, and social. Under the agronomic category, the addition of biochar increased livestock production in terms of yield, the fertility of the soil, the fecundity of animals, and reduced the use of inorganic inputs. Also, when biochar is used in the soil or fed to animals, less methane is emitted. Environmentally, feeding biochar mixtures to livestock helped sequester carbon, reduce greenhouse gas emissions, and reduce the amount of pathogens found in water. Relating to the social aspects of the benefits, biochar increased the animal's welfare. Biochar does this by helping with the animal's rumen fermentation, which is the process in which food is digested and converted into energy.

CharLine is an Austrian company that makes different biochar mixtures specific to different animals. They currently make a range of products for different animals, such as cattle, calves, sheep, and pigs (CharLine, n.d.). CharLine is in the middle of creating a biochar mixture for poultry. Not only can CharLine's mixtures help the animals' rumen fermentation, but it can help with a lot of different issues that can occur. An overview of the different problems the biochar mixtures can help with for each animal are shown in Table 4.

Table 4. Effects of feeding CharLine's biochar mixtures to different animals.

Animal	**Effects**
Cattle	Decreased need for antibiotics

Calves	Decreased stress from separating from mother, other stress
Pigs	Decreased stress after weaning piglets or adjusting from no milk from mother, reduced tail-biting
Sheep	Decreased diarrhea
Poultry	Goal: to replace antibiotics

All of CharLine's feeding mixtures contain about .5% biochar, which is a very small amount. Currently, they are selling most of their biochar mixtures in 3.5 kg buckets that cost $56.14 AUD (CharLine, n.d.). For the cattle, there is a 9 kg bag for $72.30 AUD, and for the pigs, there is a 10 kg bag for $64.24 AUD and a 400 kg BigBag for $901.03 AUD (CharLine, n.d.).

4.4.2 China

China's biochar market is unique in that it is the only market in the world where biochar is produced on an industrial scale. In China, there are 110 biochar producers generating 200,000 tonnes of biochar per annum– 20 less producers than in the United States producing greater than double the amount of biochar (Meng et. al., 2019). However, according to Dr. Stephan Joseph, who has a lot of knowledge about the Chinese biochar market, China could be producing up to 1,000,000 tonnes of biochar per annum. This is because people in China are both producing and using biochar, but not telling anyone. The volume of Chinese production supersedes any other production around the world, and they are growing rapidly. China built 20 different $2 million, 30 kiloton per year biochar plants in 2018– one every 3 weeks. 45 more plants are under construction, with 200 more being planned (Draper, 2018).

There are a lot of different applications for biochar in China, depending on how the biochar is made. For example, conventional hardwood and bamboo biochar is being used in food medicinal applications, with 20,000 to 60,000 tonnes being produced per annum. Another application is in the tobacco industry. In this case, the high quality biochar can be sold for around $600 USD per tonne. Another application has recently become popular is the production of biochar-based fertilizers. Lastly, Dr. Stephen Joseph visited a plant that uses rice husk as a feedstock and gasification as a process. This produces a biochar that has a low amount of carbon and a high amount of silica ash, and it is used both in the steel industry and the production of bricks.

According to Dr. Stephen Joseph, there is a certification for biochar in China. It is a province-based standard, although he was unsure if this was just a Beijing standard or a state standard. However, when making biochar-based fertilizers, the producers just need to follow the fertilizer standard, not the biochar standard. Since there is possibly 800,000 tonnes of biochar produced that is unaccounted for, it is hard to believe that most producers are certified. Despite the apparent lack of certification enforcement, there is government support for the biochar industry in China. For example, farmers can get paid for their residues, which are then used as feedstock to produce biochar. In terms of getting more biochar plants up and running, the regulatory system is faster, allowing for more plants to start up. There is also government support in terms of doing more research into biochar and its possible applications.

4.4.3 South Korea

Most of the developments from South Korea are currently in the research stage. Bilal Aftab of Sejong University is researching techniques on how to remove organic foulants from landfill leachate. As water becomes a scarce resource, the research has paved a path to further look into biochar in water treatment applications. When biochar is combined with forward osmosis system, it was shown to decrease the contaminants in the leachate (Aftab, Ok, Cho, & Hur, 2019). The current results are promising, in regards to replacing the current method of leachate treatment, which is evaporation. Other researchers from Hanbr National University are researching ways to turn Korean cabbage waste into biochar. Then they compared its effectiveness with activated carbon. The results showed that biochar made from cabbage waste held less absorptivity compared to activated carbon for anionic solutions. However, biochar had a higher absorptivity of cationic solutions compared to activated carbon (Sewu, Boakye, & Woo, 2017). These properties are very good for wastewater treatment. They have industrial viability to be used to treat cationic dyes in certain applications and it can be done affordably. Despite this research, there is no concrete data that assesses the size and volume of the biochar market in South Korea.

4.4.4 Norway

The biochar market in Norway is relatively new, so there is not much known about it. However, Norway has the potential for the market to develop quickly. Norway has an excess amount of biomass that can be used as feedstocks. Firewood, wood chips, logging residues, thinning residues, and stumps from clear cuttings are majority of Norway's biomass feedstocks (Tromberg, 2015). Another reason for an increased development of the biochar industry is the amount of government support behind it. Norway already has services where farmers are paid eco-friendly practices. However, Norway also a service specific to biochar, where the government will pay for 50% of all biochar plant installations (NIBIO, 2018). This kind of government service encourages people to start producing, and using biochar. Despite this support, there are reasons that hinder the development of the biochar industry in Norway. Some of these include limited technology availability and communication with stakeholders (NIBIO, 2018).

One organization, the Norwegian Institute of Bioeconomy Research (NIBIO), has done the most research into biochar in Norway. As part of a research project in 2017, NIBIO helped orchestrate the development of Norway's first biochar plant at the Skjaergaarden nursery (Lewis, 2017). The plant is designed to be small-scale and can be used by everyday farmers. The biochar would be mixed with compost, as a way of retaining nutrients in the soil. In June 2017, the nursery invited more than 70 people, including representatives from private and public sector organizations and the agricultural sector, and research scientists, and held a demonstration that showed how the plant would work (Lewis, 2017). These demonstrations help show stakeholders how biochar works and how beneficial it can be.

4.5 Potential Biochar Markets in Australia

4.5.1 Biochar as a Fertilizer Additive

Compared to the rest of the world, the market for fertilizer in Australia is small. The International Fertilizer Association estimates that Australia consumes on average of 5.4 million tonnes of fertilizer, which is comprised of 1 million tonnes of nitrogen (N), 400 thousand tonnes of phosphorus (P), and 200 thousand tonnes of potassium (K) based fertilizer (Fertilizer Australia, 2019). These compounds can be found in the major fertilizers that are sold around the world. Some of the products that are sold worldwide and their N, P, and K breakdowns can be found in Table 5.

Table 5. Fertilizer products and their associated N, P, and K content (Adapted from Fertilizer Australia, 2019).

Product	Nitrogen %	Phosphorus %	Potassium %
Urea	46		
Ammonia	82		
Sulfate of Ammonia	21		
MAP	10	22	
DAP	18	20	
Single Superphosphate		9	
Muriate of Potash			50

Fertilizer increases the productivity of the soil, allowing for the growth of more food. However, after prolonged use, they begin to damage the soil, requiring even more fertilizer use to counteract this effect. There is a potential for biochar to help mitigate the damage of this effect. Biochar has been observed to improve the productivity of soils when mixed with fertilizer. Dr. Bhatta Kaudal (2019) of the University of Melbourne has found that when biochar is mixed with fertilizer, plant growth increases. Intriguingly, a side benefit found decreased leachate, or loss of N, P, and ammonium from the soil. The combination of 20% biochar and fertilizer had the best effect of mitigating this effect. There has been a 5% to 80% reduction in the loss of nitrogen after the addition of biochar (Bhatta Kaudal, 2019). Research completed by the Department of Agriculture of Australia (2019) shows that biochar can reduce "emissions of nitrous oxide from fertilizer application."

This is promising because there is a potential market for biochar, where it can be added to fertilizer to increase its benefits. Because the size of the fertilizer market in Australia is smaller compared to the rest of the world, there is a possibility for it to be implemented in the larger global market. The ability to make fertilizers with 20% biochar could lead to around 1.08 million tonnes of biochar being used. This allows there to be a potential for a market, based on the limited data available on the bulk sale of biochar. Using $300 AUD as a starting figure for bulk sale, this was determined based on the low-end consumer market prices given by Tom Miles of the IBI as a conservative benchmark. This leads to a potential market size of $324 million AUD. This, of course, is an estimate on the market side. The need for a standard bulk price can be found in the Recommendations section.

4.5.2 Biochar as a Concrete Additive

According to the Australian Cement Industry (2018), approximately 10 million tonnes per year of concrete was produced in 2017-2018. In the mixing of concrete, cement is generally mixed with pebbles, fly ash, and sand to produce industrial concrete. Recent studies conducted in Singapore have shown that there is a possibility for biochar to be added to concrete. A summary of the process is shown in Figure 11.

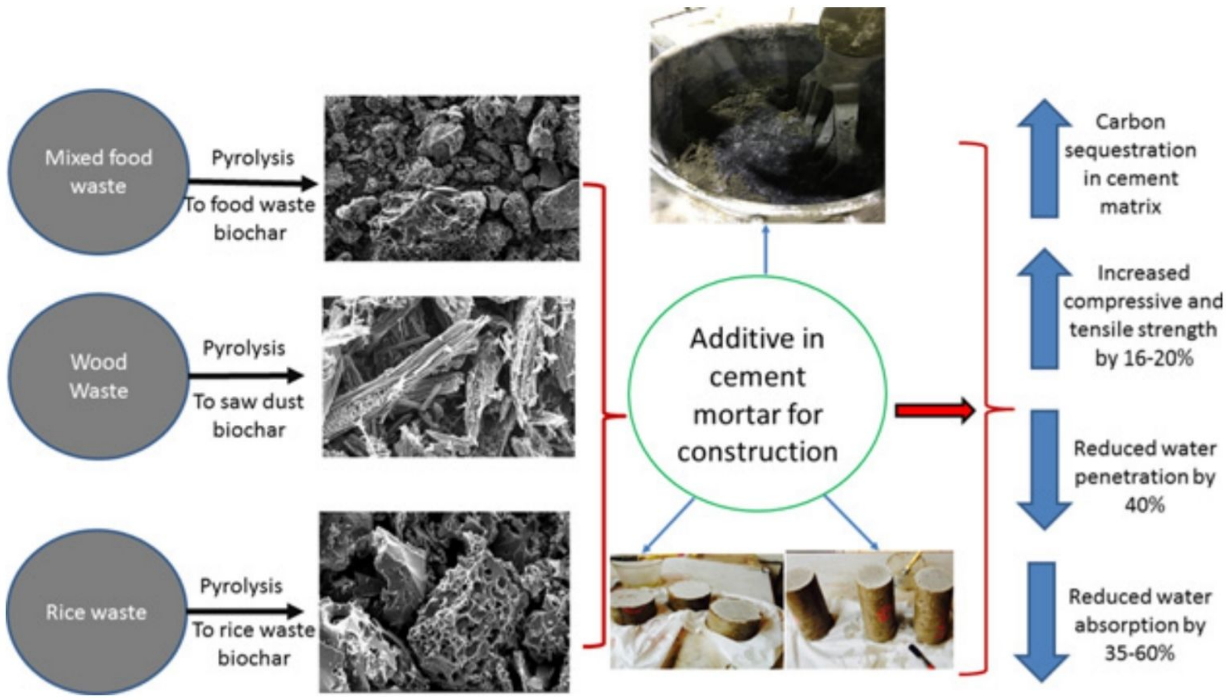

Figure 11. Process and benefits of biochar as an amendment in cement (Gupta, Wei Kua, Jun Koh, 2017).

When 1%wt. biochar was added to the concrete, it was observed that the 90-day strength of the concrete was improved, leading to shorter curing times, with compressive strength data shown in Figure 12 (Gupta, Wei Kua, Jun Koh, 2017).

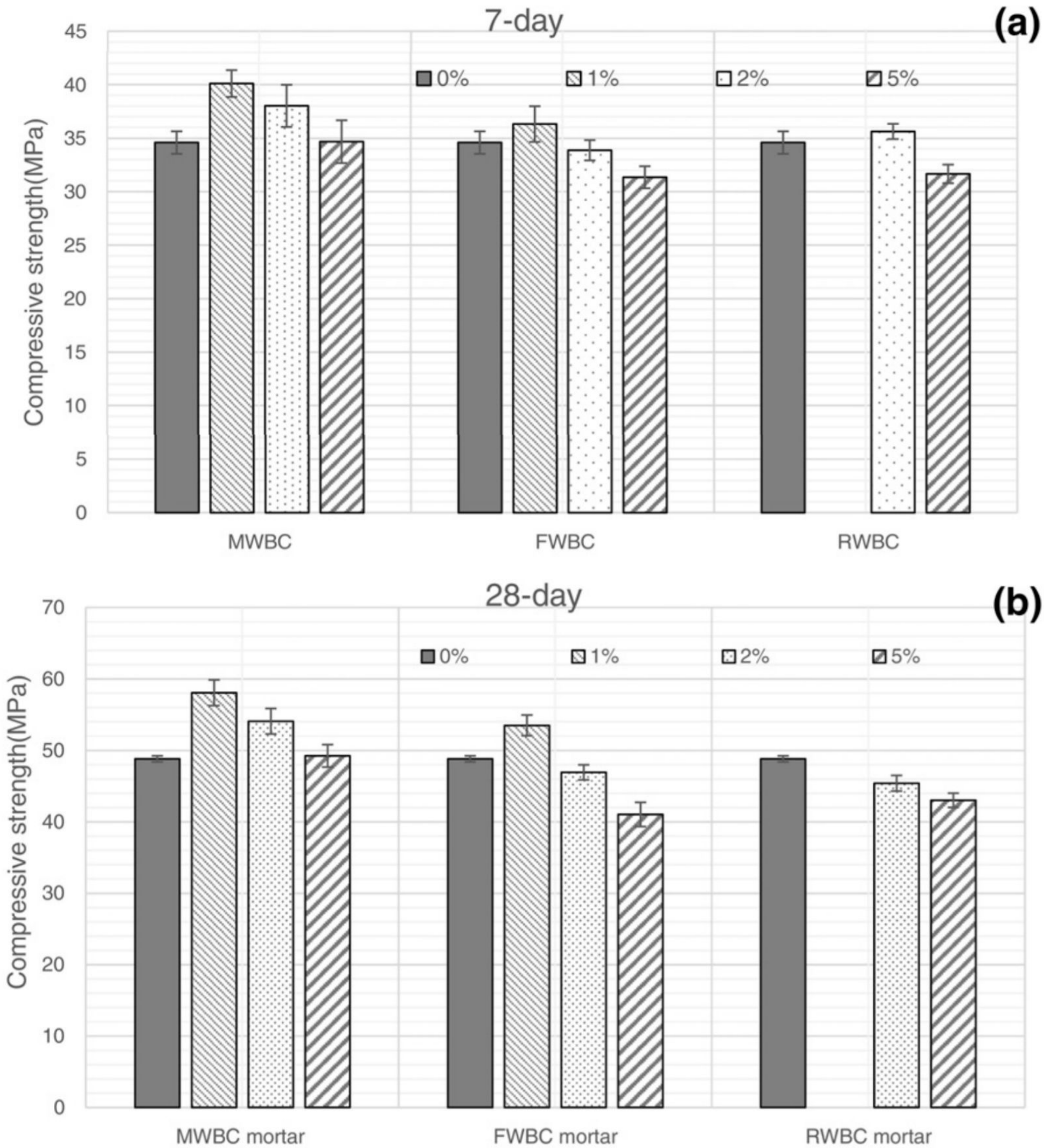

Figure 12. Compressive strength of different mixes of biochar into concrete at 0, 1, 2, and 5% after 7 and 28 days. MWBC stands for mixed wood biochar, FWBC refers to food waste biochar and RWBC stands for rice waste biochar (Gupta, Wei Kua, Jun Koh, 2017).

With biochar being able to increase the strength of the concrete and its ability to decrease the amount of net CO2 being emitted by the concrete, there is the possibility of biochar being included in the massive concrete market. It also allows for concrete to reduce its CO2 footprint.

With biochar making 1% of 10 million tonnes, that would make for a potential market of 100,000 tonnes of biochar per year. Using the $300 AUD price as a conservative standard figure for bulk sale, it would make for a potential market of $30,000,000 AUD. This potential product stream also allows for the biochar to be further expanded in the global concrete market. The leader of concrete production is currently China, at over 2.3 billion tonnes per year (US Geological Survey, 2019). The geographical position of Australia allows there to be a potential for biochar to enter the market in China as a concrete additive.

5. Key Insights

In the United States, the biochar market is still in a boutique phase. Biochar succeeds in places where there is a specialised, generally small, group of people that have an interest in aligning with a very specific product; just a few companies are developing products. Whether it be with feed additives, stormwater filters, or soil amendments, biochar is rarely sold in bulk (> 5000 tonnes per year). The Australian biochar market is even younger than the United States market, and still has a great many holes in its knowledge framework.

Australian biochar is most often thought of in terms of how it benefits the soil; this makes sense as there as the water retention properties of biochar make it great for drought-stricken land. However, biochar's market value is limited if its value is tightened to just one value stream. Biochar has vast potential because it is accompanied by a myriad of benefits that have the potential to add value to numerous existing markets– the activated carbon and concrete markets are worth 60 million and 2.4 billion respectively (Nigel Murphy, personal conversation, 2019); (Australian Cement Industry, 2018).

A key way forward for biochar is to penetrate as many markets as possible to maximise value-added streams for biochar producers. Holes in the Australian biochar market knowledge need to be realised in order for market penetration to flourish. If a sufficient knowledge platform can be established, then there will be a more clear way forward into the biochar market– a solution that this report seeks to explore.

6. Recommendations

There is a knowledge problem as it pertains to understanding the complexities of a biochar market in Australia. A primary recommendation is that an Australian version of the USBI Dovetail Report should be established to address the current knowledge holes that exist in the biochar space. Investors will be more inclined to enter the market if they know precisely where, and how, biochar is being used in Australia. Such a report would likely benefit from Southeast Asia's inclusion, since the 4,340,700 km^2 land area region is home to 650 million people (United Nations, 2019). A sufficiently funded consultation report will also illuminate profitable pathways into markets that are complementary to biochar.

Expanding into as many value-added streams as possible is a benefit to the longevity of biochar as an integral component of future sustainability-centered economies. Diversification is a point of paramount significance in biochar's development because there is resistance in many of the markets where biochar is most effective. For instance, it is extremely difficult to bring new products into the retail garden market where there are already many products "on the shelf." As a result, it is often best to minimise risk and create many value-added products from as many viable waste streams as possible. Creating a variable set of value-added products from biochar also helps establish name recognition with the consumer in an industry where familiarity often takes precedence over objectivity.

Like with the aforementioned information holes on the part of biochar investors and producers, biochar faces a knowledge problem with consumers. If a given process is dubious to the investors and innovators behind the product, then the customers, whether it be wholesale retailers or small-volume customers, are going to have a hard time paying for the product. This is especially so if the product is sold at an elevated unit price compared to alternative, more familiar, options. Biochar is expensive, but can succeed if its productivity becomes commonplace in the minds of consumers. This is to say that if the biochar brand becomes synonymous with higher quality and performance, then it will have a place "on the shelf" next to cheaper alternatives. A holistic marketing initiative might be the answer to making biochar a higher profile product. Turning biochar into sustainability-branded commodity should be a priority as clean and renewable solutions gain greater prominence in various complementary markets.

A biochar certification process should be established in Australia to facilitate its introduction to the market as a commodity. The distinct lack of an Australian certification causes issues in specifying the end product. Biochar consumers will inevitably have a difficult time comparing competing biochar products, since there is no standard methodology for preparing a specified biochar product. If the biochar market is to mature, then it is going to have to establish certifiable products to aim for as well as a standard set of procedures to get there– having one without the other only stunts the growth of the market. More information about the certification process and makes for a good certification can be found in Appendix E.

Anticipating a successful certification and growth stage, an analysis on the scalability of the biochar market should be organised. There is very little data that projects what the biochar market might look like scaled up to a competitive level. Even in China, where there is the biggest industrial push for biochar, there is very little data on what might happen to the biochar market under significant market expansion. While the absence of this data will not cripple the early development of the biochar market, it would be missed in the event that the market were to grow faster than anticipated. Such a task could be carried out by looking at the history of developing markets that are similar in nature to biochar. Analyzing the way in which other markets of similar standing have scaled up can help predict the where ,and when, time and effort should be spent.

Hans-Peter Schmidt's "55 Uses of Biochar" (2019) lists 50, not 55, value-added products for biochar. A sufficient way forward into the biochar market would be to assemble a detailed version of this list with significant insight into each pathway. Each stream on the list might have a two-page write up with market drivers, trends, and projections. In doing so, the most worthwhile biochar product streams can be more readily identified. The process could be carried out on a smaller scale as well wherein only a dozen targeted streams are highlighted and ranked based on desired parameters.

As biochar moves out of its infancy in Australia, there needs to be a solid framework from which to launch from. Thereafter, innovators and thinkers that began the biochar movement need to continue diversifying and expanding the biochar brand into one that is globally recognizable. Biochar's benefits are as impactful as they are numerous: it has the capacity to change the way that the world thinks about the future of sustainable solutions.

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9. Appendices

9.1 Appendix A: Summary of "55 Uses of Biochar" (Schmidt 2019)

50 Uses of Biochar

<u>Biochar in Animal Farming</u> ● Silage agent ● Feed Additive/supplement ● Litter additive ● Slurry Treatment ● Manure composting ● Water treatment in fish farming
<u>Use as a Soil Conditioner</u> ● Carbon fertilizer ● Compost ● Substitute for peat in potting soil ● Plant protection ● Compensatory fertilizer for trace elements
<u>Use in the Building Sector</u> ● Insulation ● Air decontamination ● Decontamination of earth foundations ● Humidity regulation ● Protection against electromagnetic radiation
<u>Decontamination</u> ● Soil additive for soil remediation ● Soil substrates ● A barrier preventing pesticides getting into surface water ● Treating pond and lake water
<u>Biogas Production</u> ● Biomass additive ● Biogas slurry treatment
<u>Treatment of Waste Water</u> ● Active carbon filter ● Pre-rinsing additive ● Soil substrate for organic plant beds ● Composting toilets
<u>Treatment of Drinking Water</u> ● Micro-filters ● Macro-filters in developing countries
<u>Divers other Uses</u>

• Exhaust filters
  ○ Controlling emissions
  ○ Room air filters
• Industrial materials
  ○ Carbon fibres
  ○ Plastics
• Metal reduction (metallurgy)
• Cosmetics
  ○ Soaps
  ○ Skin-cream
  ○ Therapeutic bath additives
• Paints and Colouring
  ○ Food colourants
  ○ Industrial paints
• Energy Production
  ○ Pellets
  ○ Substitute for lignite
• Medicines
  ○ detoxification
  ○ Carrier for active pharmaceutical ingredients

Textiles • Fabric additive for functional underwear • Thermal insulation for functional clothing • Deodorant for shoe soles
Wellness • Filling for mattresses • Filling for pillows • Shield against electromagnetic radiation

Source: http://www.ithaka-journal.net/55-anwendungen-von-pflanzenkohle?lang=en

9.2 Appendix B: Summary Tables of Case Studies in 2019 ANZBI Report

Doug Pow: Beef Biochar	**Potatoes: Ballarat**	**Biochar Now: Golf Courses**
• Mixed with molasses and feed to cattle • Trialled as a substitute to a regime of hay feeding, along with pasture fed grass • **User net benefit per tonne of biochar: $1,700** • **User cost: $1,000 (per 60 cows)** • **Payback: less than a year**	• Trial to determine the effect of biochar on Nadine see potato yields • Biochar: mix of wheat straw and poultry litter and conditioned with phosphoric acid (reduced pH to 6.8) • **Biochar application increased total yield of potatoes per hectare by 53%** • Using 20% biochar mixture was the best treatment • **User net benefit: $8,000 per hectare** • **User cost: $160 per hectare** • **Payback: less than a year**	• Feedstock: woody biomass • Maximum current annual biochar production: 450 metric tonnes • Applied raw at a rate of around 2% at the root zone • **Reduces irrigation bills by $300,000 to $500,000** • **Reduced use of water and fertilizer by 50%** • **User net benefit per tonne of biochar: $22,600** • **User cost: $200,000** • **Payback: less than a year** • **Years of effect: 10 years**

Brookton, WA: Saline Soil Remediation	**Geraldton: Cucumbers**	**New South Wales: Biochar as a Feed Additive**
• Permeable biochar wells were established to reduce the impact of salt on tree growth and improve soil health • 5 treatments were trialled with jarrah wood biochar mixtures in 5 trenches • Trees were planted in front of each treatment	• 2016 poultry litter trial with Energy Farmers Australia • Considering the effect of biochar on nutrient availability, plant health, and yield • 6 different treatments, 4 with varying amounts of biochar and fertilizer, 2 with just biochar • Best treatment, in	• Test the effect of biochar on cattle weight gain • Used jarrah wood biochar transported from WA ($500 per tonne) • 2 different feeds: 1 with no biochar, 1 with 1% biochar • **Over 2 month period, cattle feed mixture with biochar gained**

• **After 1 year: soil salinity levels were reduced, along with the other agricultural benefits of biochar**	terms of yield, user cost, and user net benefit per kg of biochar: low rate of biochar and low rate of fertilizer • **Best treatment user net benefit per kg of biochar: $52** • **Best treatment cucumber yield: 1205 kg per row** • Treatments with just biochar were the worst	**10.4% more weight** • More cattle refused to eat the biochar feed than standard feed, most likely due to biochar reducing the odor of the grain, making it less attractive to the cattle • **User net benefit per tonne of biochar: $4,800** • **User cost: $3.57 per head** • **Payback: less than a year**

Lambells Lagoon: Zucchini
• Investigating the potential benefits of applying biochar for horticultural production in Northern Territory, specifically relating to biochar's effect on crop yield and soil characteristics • Used biochar produced by Earth Systems using woody biomass as the feedstock • 4 separate trials: 1 with fertilizer (control), 1 with 5.3 tonnes of biochar per hectare, 1 with 13.25 tonnes of biochar per hectare, and 1 with 21.2 tonnes of biochar per hectare • **13.25 tonnes of biochar per hectare led to greatest overall yield surplus of 25% relative to control** • **Farmers also said the produce improved in terms of health, size, and appearance** • **User net benefit per tonne of biochar: $730** • **User cost: $1,000** • **Payback: less than a year**

Source: Robb, S., & Joseph, S. (2019, June). A Report on the Value of Biochar and Wood Vinegar: Practical Experience of Users in Australia and New Zealand. Retrieved November 24, 2019, from https://www.anzbi.org/wp-content/uploads/2019/06/ANZBI-2019-_-A-Report-on-the-Value-of-Biochar-and-Wood-Vinegar-v-1.1.pdf.

9.3 Appendix C: Summaries of ANZBI Conference Sessions

Doug Pow of Powbrook Farms

Doug Pow is a farmer based in Manjimup, Western Australia. Primarily he raises cattle, though he also farms avocados. Doug mixes one third of a kilo of biochar per cow into the cattle feedstock each day. The biochar passes right through the cattle's digestive system. This has a few advantages. Biochar enables the cattle to run at higher stocking, fertility and growth rates. It also has environmental and animal welfare benefits because it helps the cows' digestion in terms of rumen fermentation which also reduces methane emissions from the cows. This represents a huge potential for mitigating climate change, as 14.5% of all anthropogenic emissions come from livestock (FAO, 2019). Benefits follow post-digestion too. The cows drop manure containing the biochar, which is subsequently buried up to 600mm down into the pasture soil by dung beetles. Not only does this remove the manure from the grazing land surface, it enables the biochar and manure to enhance the soil health. The manure contains nutrients for the soil and the porous biochar acts as an excellent growing medium, increasing the carbon content in the soil and increasing water retention. All together the result is that the availability of fertilizing minerals, particularly phosphorus, but also potassium, sulfur, and calcium is increased. It also raises soil pH and increases the proportions of legumes in soil.

Doug also experimented with avocados and biochar. He planted two rows of avocado trees, one with biochar and one without. He planted twelve trees using varying mixes of biochar and soil. He planted four trees each at 5%, 10%, and 20% biochar in the soil. Each tree had a control in the other row. Five years on, the biochar trees all grew bigger and had better root structures. The soil mixed with biochar had greater biological activity than that without. The carbon content soil of the biochar row rose from 4.5% to 13.5% and continues to rise, even without adding more biochar. Most importantly perhaps is the difference in yield. On average the biochar trees produced 2.65 times more fruit than the other trees.

According to Pow, other nearby farmers picked up on the great success he had with biochar and began to implement biochar into their own farms. Doug sourced the biochar from a silicon company that produced it from their waste, and according to Nigel Murphy, Doug was buying the char for only $150 per ton. This represents a much lower price point than is typical, so the profits Doug may have realised should be taken with a grain of salt. Despite this Doug notes that the local demand for biochar grew so much that the silicon factory could not provide enough biochar, so it is being sourced from other locations as of now.

Sources:
ANZBI Conference
Video on Doug Pow from the South West Catchments Council:
https://www.youtube.com/watch?v=_JPoItRWYSQ
LiveStock Emissions from Food and Agriculture Organization of the United Nations:
http://www.fao.org/news/story/en/item/197623/icode/
Our own Interview with Nigel Murphy

Biochar from biosolids microwaved-pyrolysis: Characteristics and potential for use as a growing media amendment

Dr. Bhawana Bhatta Kaudal of Melbourne University argues that using microwave pyrolysis technology is a more energetically efficient method of producing biochar than with traditional convective heating. Microwave energy is viewed as more optimal for biochar production from biosolids because of its naturally high moisture content. Moisture transport out of the heated material leads inhibits the convective heating process because of evaporative cooling (Crank, 1979; Henry, 1984). The interactions of electrical fields of the microwave and material make the microwave process faster than convection based pyrolysis, and the hot vapors resultant from the moisture in the material actually contribute to the heating of the biosolids rather than hinder it (Brodie, 2007). Another benefit of microwave pyrolysis particular to biosolids is the preservation of some of the functional groups making up the feed. This makes the resulting bio-oil less environmentally dangerous, and means it can be processed further into more valuable products than if the functional groups were destroyed. The downsides of using a microwave include a necessity for adding a microwave susceptor to kick off the process and the non-uniform nature of microwave heating. Bhatta notes however, that after the first batch of biochar is created some can be recycled as the susceptor for the next batch, eliminating the need to purchase it except for startup.

The actual demonstration unit had the following specifications. The microwave chamber was 1 cubic meter in volume and operated at 6000 W and 2.45 GHz. The mass of the sample was approximately 2.34 kg. The unit built and used is shown in Figure 13.

Figure 13. Microwave pyrolysis unit created and tested by Dr. Bhatta (2019).

Initially the biosolid was treated in a food blender for 30 seconds to break it up and mixed with biochar from previous experiments as a susceptor. The added biochar was 10% of the mass of biosolid. This mix was placed into a four liter, air-tight crucible within the microwave chamber to limit exposure to oxygen. Since the experiment focused on the biochar the syngas and bio-oil where vented to the atmosphere. Overall the experiment took 30 minutes to run, much faster than traditional pyrolysis which usually takes several hours. Characteristics of the products are shown below in Table 6.

Table 6. Chemical characteristics and energy values for pyrolysis products.

Product	N	C	H	S	O	Ash (%)	Yield ($g\,g^{-1}$)	HHV ($J\,g^{-1}$)	Energy Recovery ($J\,g^{-1}$)
	(%)								
Bio-oil	4.822	73.543	9.838	0.644	11.153	0.000	0.024	36425	860
Biochar	0.700	11.800	0.000	0.530	4.370	82.600	0.599	2342	1400
Syngas[a]	6.674	46.378	10.813	1.849	34.286	0.000	0.377	25684	9680
Initial Biosolids	3.050	26.300	4.310	1.030	15.810	49.500	1.000	13324	–

As shown, the yield was primarily biochar, coming in at just under 60%. The rest of the mass almost entirely became syngas making up almost 38%. Bio-oil made up the last 2.4%. Energy-wise, industrial microwave systems operate at approximately 75%-80% efficiency therefore the net electrical energy requirement was between 9000 and 9600 J/g biosolid. The recoverable energy from the syngas of 9680 J/g could be used to offset the energy demand.

The next stage of the experiment was to determine the biochar's usefulness as a growing medium additive. Bhatta tested several combinations of biochar, composted pine bark and fertilizer. The mixes were 80% pine bark and 20% biochar with fertilizer (MB20_F), 40% bark and 60% char with fertilizer (MB60_F), and lastly 40% bark and 60% char without fertilizer (MB60_NF). The same amount of fertilizer was regularly added to the media designated to use fertilizer. Leachate was collected from each of the plant pots weekly and analyzed for nitrates, ammonium, and phosphates. The media itself was sampled at the beginning and end of the experiment while the shoots and roots were sampled at the end. The results of the dry weights of the roots and shoots are shown below in Figure 14.

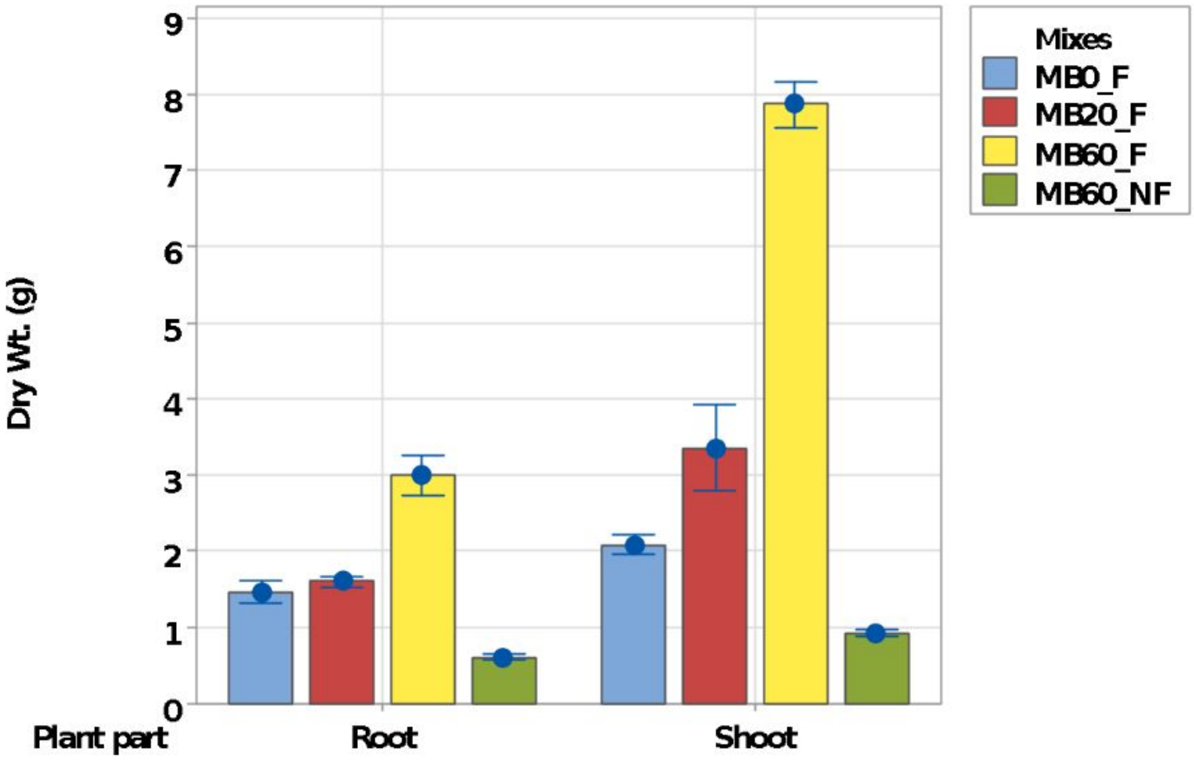


Figure 14. Root and shoot dry weight for silverbeet plants grown for 11 weeks.

The shoot and root data demonstrated that the most favorable mix by this measure was clearly the 60% biochar with fertilizer mix. It is important to note that without fertilizer the 60% biochar mix performed the worst by this metric, demonstrating that biochar is not a replacement for fertilizer, but a substrate that enhances the fertilizer's efficacy.

The leachate data revealed that the 20% biochar mix with fertilizer lost the least nutrients across the board for ammonium, nitrates and phosphates. With the other mixtures performing variably across the different minerals. This shows that it is very possible to use too much biochar, so careful consideration should be given to the ratios of biochar, fertilizer and growing medium.

Sources: J. Crank (1979). *The Mathematics of Diffusion*. J. W. Arrowsmith Ltd., Bristol.

P.S.H. Henry (1948). *The diffusion of moisture and heat through textiles,* Discuss. Faraday Soc.,
3, p. 243.

G. Brodie (2007). *Simultaneous heat and moisture diffusion during microwave heating of moist*
wood, Appl. Eng. Agric., 23, p. 179

Bhatta Kaudal, B., Aponte, C., & Brodie, G. (2018). *Biochar from biosolids microwaved-pyrolysis: Characteristics and potential for use as growing media amendment. Journal of Analytical and Applied Pyrolysis*, 130, 181–189. https://doi.org/10.1016/j.jaap.2018.01.011

9.3.1 Local Climate Crowdfunding By Pia Piroschka Otte

Pia Otte opened her talk by stating that the is a knowledge problem in regards to biochar. Farmers in the scandinavian area lacked the full knowledge of the benefits of biochar. Through her research she found that most farmers wanted to have their own pyrolysis units on site so that they could control the composition of the biochar and ensure its quality. One of the techniques to fund such projects she had discussed during the talk was crowdsource funding. The 4 models of crowdsource funding were donation, reward, lending, and equity. Donation involve people giving to the cause expecting nothing in return. In the reward model the funder expects some type of merchandise in return for their contribution. In the lending model the funder is the bank or a collective group funding the project. The last model equity allows the funder to get a stake of the company. She had stressed that farmers hesitate to change and need a story to really convince them. Farmer really trust their peers and to see another farmer take initiative is really powerful. Some of the first steps to establish local crowdfunding action she said to take were:

- Public Research
- Find pioneers
- Identify farmers
- Identify committed people.

The idea behind these points is that real people and real stories are the most effective way to get across to the farmers.

Source:
ANZBI conference

9.3.2 Development of a Pacific Northwest Biochar Atlas - Kristen Trippe

At the start of the talk Kristen Trippe made sure everyone was on the same page about what biochar is and that Biochar is similar to black carbon and activated charcoal. She discussed some of the reasons why farmers are not using the biochar currently or more on why their is a lack of knowledge in the area of biochar. The vast majority of a biochar particle is made up of stable carbon that can react with the surrounding water and soil to provide fertility, absorb water, increase cation and anion exchange capacity, and bind environmental toxins. A biochar particle also has volatile carbon which is a good source of food for soil microbes, and ash, which can contribute to P, K, and Ca to depleted soils. One of the key points that was brought up is that not all biochar is the same. Biochar from different sources have different carbon content and have different effects as a soil amendment. The contents are also dependent on the speed of which the biochar is pyrolyzed and the temperature of the process. The image below shows many types of chars that have been analysed for their composition.

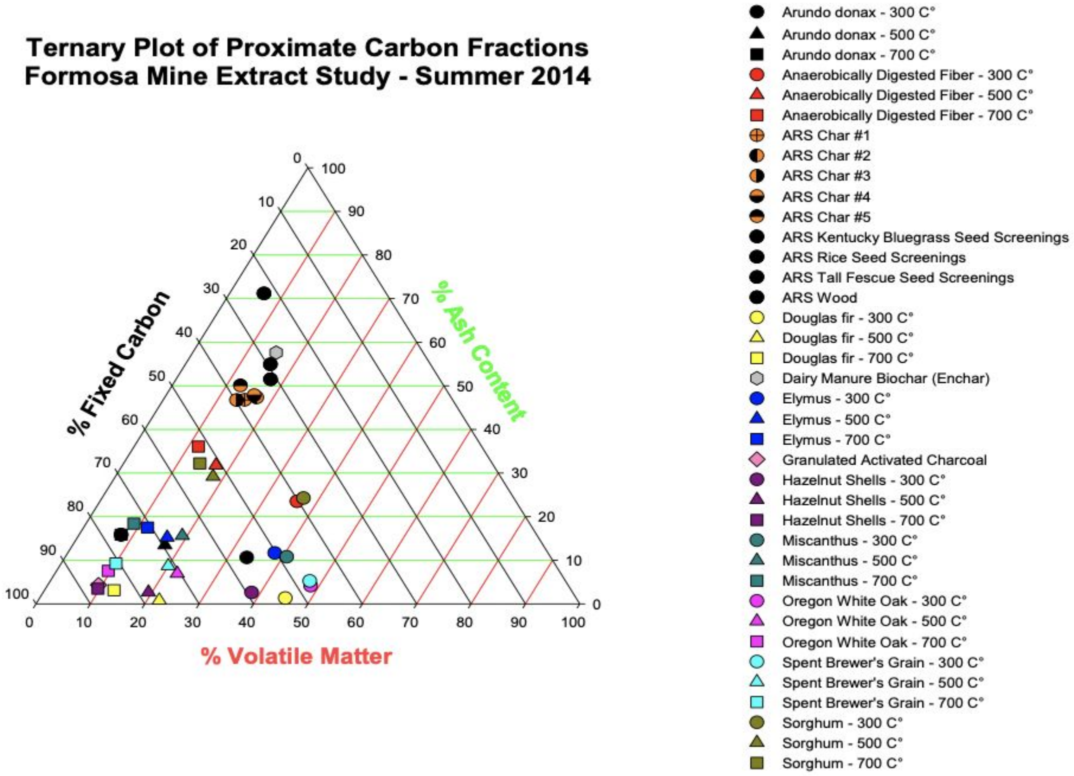


Figure 15. Different compositions of biochars

The point that was brought across was how do farmers decide what biochar to use and in what quantity. The research team work together to publicise the benefits of biochar like:

- Builds healthy soil

- Sequesters carbon
- Reduces acidity
- Retains nutrients
- Increases soil microbial abundance

This was done in collaboration with an atlas tool that took the soil properties of an area and combined that with the properties of the farmers. Thus it was able to point the farmer in the direction of the biochar they may want to use based on the soil data and priorities. After, it had instructions on how to apply the biochar and the estimate pricing for the kind of biochar.

Source: ANZBI conference

9.3.3 Biochar and Dung Beetles

Melissa Rebbeck is the director of her company Climate & Agricultural Support Pty Ltd., as well as a farmer, from Goolwa, South Australia. She conducted two different trials involving biochar. The first experiment was testing the effects of feeding biochar to cattle on the dairy products they produce. For this trial, she fed four dairies of 250 cattle. One dairy was fed 90 mL/head/day of biochar and other additives, one dairy was fed 200 grams/head/day of Mara Seeds biochar, and two dairies were fed mixtures with no biochar. For six weeks, the milk yield, protein, fat, and the individual cow cell count (ICCC) was measured once a week across all four dairies.

Over the six weeks, Melissa found that the cattle fed the mixture with the Mara Seeds biochar had the greatest increase in terms of milk yield (2L/head/day), protein, and ICCC. In comparison, the cattle fed the other biochar mixture had a decrease in terms of milk yield. Additionally, by feeding cattle the Mara Seeds biochar mixture, the dairy's profit increased by $130,000/year. By comparing the two different biochars used in the trial, Melissa came to the conclusion that Mara Seeds biochar might work better because it included less additives in the mixture and it had a better feed conversion.

One key finding that came out Melissa's first trial was that the biochar was not digested, but ended up in the dung, or manure, of the cattle. So, she wanted to test the effects of her last experiment on soil. This experiment involved three different trials: biochar and dung beetles (from the first experiment), biochar with nitrogen fertilizer, and biochar with organic fertilizer. Based on her calculations, she found that it would take one year for 6 tonnes of biochar and 365 tonnes of dung to be buried with 50 cows. After the experiment was completed, Melissa found that feeding biochar to cattle in the presence of dung beetles helped increase carbon content in the soil, increase soil moisture holding capacity, improves production, reduces methane emissions, and reduce the depended on nitrogen fertilizers, in comparison to the other biochar mixtures tested.

Along with these two experiments, Melissa also outreaches to farmers to gauge their interest in using biochar on their farms. While others find it hard to get farmers interested in using biochar instead of other soil fertilizers, she is able to relate to them since she is a farmer herself. Melissa offers them the opportunity of having conducting a trial using biochar in their soil to see how biochar actually works. According to Melissa, most of the farmers she has done this with have continued using biochar, thus becoming early adopters and encouraging other farmers to try biochar as well.

Source: ANZBI Conference

9.3.4 Feeding Biochar Mineral Complexes to Animals

Professor Stephen Joseph is a renewable energy and biochar researcher and consultant at the University of New South Wales in Sydney, AU. His research involved looking into the effects of biochar on the role of biofilms, which line the walls of the rumen, on the conversion of feed and production methane. He found that biochar will help reduce methane production and increase nutrient availability by catalyzing biotic and abiotic reactions in the biofilms it is absorbed by. Biochar will also change the pH and Eh in the bulk of the rumen, thus resulting in the decomposition of the feed.

Professor Joseph based his recent research on a Canadian study that focused on the effect of biochar (from Cool Planet) on rumen fermentation and methane production in an artificial rumen that was fed a barley-silage based diet. This experiment involved 4 treatments with different amounts of biochar: 0, 5, 10, and 20 grams. The experiment lasted 17 days, with the last 7 days being the only time data was collected. It was found that including biochar to this type of diet improved the rumen fermentation of the artificial rumen and reduced methane production. The lowest methane production was achieved by the 5 gram biochar mixture.

With the conclusions from the Canadian study, Professor Joseph and others conducted their own experiment to test the effects of hardwood biochar on rumen fermentation and methane production using a rumen simulation. They tested the effect of hardwood biochar biochar on dry matter digestibility, pH, and methane production, in comparison with biochar supplementations of 800 mg/day and 400 mg/day. Professor Joseph and his colleagues found that the hardwood biochar had no effect on any of the three categories, while the biochar supplementation of 800 mg/day reduced methane production more than the biochar supplementation of 400 mg/day.

Professor Joseph is currently working on a study funded by Meat & Livestock Australia, to test the effects of feeding mineral complexes to animals. He is completing this experiment in collaboration with Commonwealth Scientific and Industrial Research Organization, The University of Western Australia, and The University of New South Wales. This is a three-year project that includes 4 stages:

1. Screening using batch cultures
2. Choosing four biochars: Two from commercial companies and two fit-for-purpose engineered biochars
3. Using the rumen stimulation to measure methane emissions and breakdown of feed
4. Testing on real animals

Right now, this study is in the middle of stage 1. By completing this study, Professor Joseph's goal is to show not only the environmental benefits of feeding biochar mixtures to animals, such as reduced methane emissions, but also the benefits on the animal's welfare, such as the rumen fermentation.

Source: ANZBI Conference

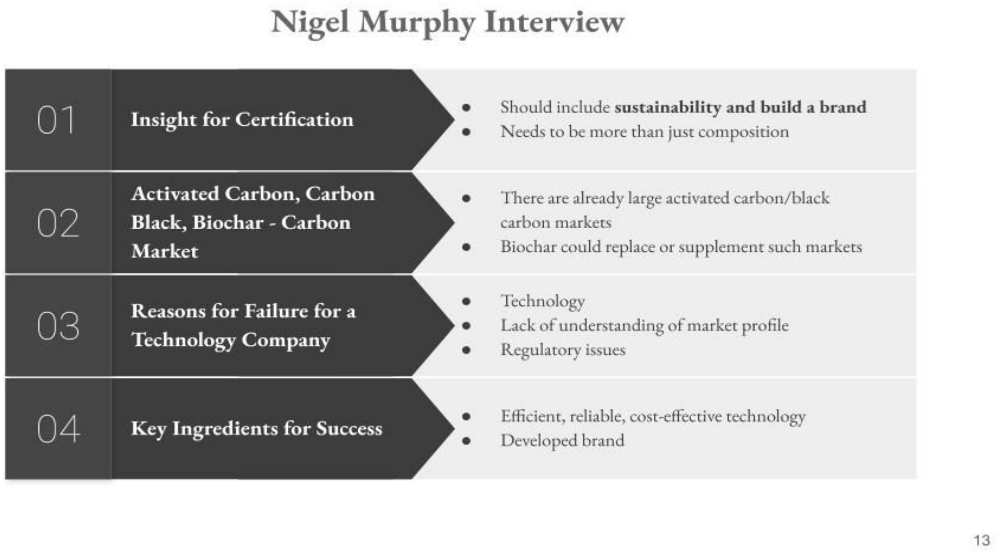
9.3.5 Tom Miles: US Biochar Initiative

Tom Miles is a director at the US Biochar Initiative, a coordinator of the Pacific Northwest Biochar Working Group, and a chair of the International Biochar Initiative. Since 2007, there have been roughly three stages of progression. From 2007 to 2012, the industry was in its exploration stage, where small-scale pyrolysis prototypes were being developed and a lot of research was being done about the benefits of biochar in soil. Starting in 2013, the early adopters started to appear and more large-scale consumer marketing of retail biochars was occuring. Since 2016, industrial production of biochar is developing and the other applications of biochar, besides being a soil amendment, are being researched. There are several types of products that can be made with biochar. Some products that can be made for agriculture, retail gardens, and horticulture farming include biochar-based compound fertilizers, biotic soil amendments, and just using biochar itself. For non-soil applications, biochar can be used in animal feeds and building materials, such as concrete.

Currently in the US, the US Biochar Initiative identified 135 biochar producers and 55 technology suppliers, with most of these coming from the Pacific West, and they are producing around 45,000 tons per year. The prices for biochar are around $350-800 (USD) per ton. Biochar is being used in retail gardening, landscaping, specifically golf courses, and on food and herb crops. Most of the biochar being made are from wood waste feedstocks through pyrolysis. However, gasification is also being used in the US, and some producers use agricultural wastes as their feedstock. The US biochar industry is currently looking into using animal wastes as a possible feedstock and using biochar as a feed additive in livestock feed. The US Biochar Initiative plans to develop an industry directory that will connect biochar users with the suppliers, and look into how producers can make biochar have the specific qualities needed for each specific application.

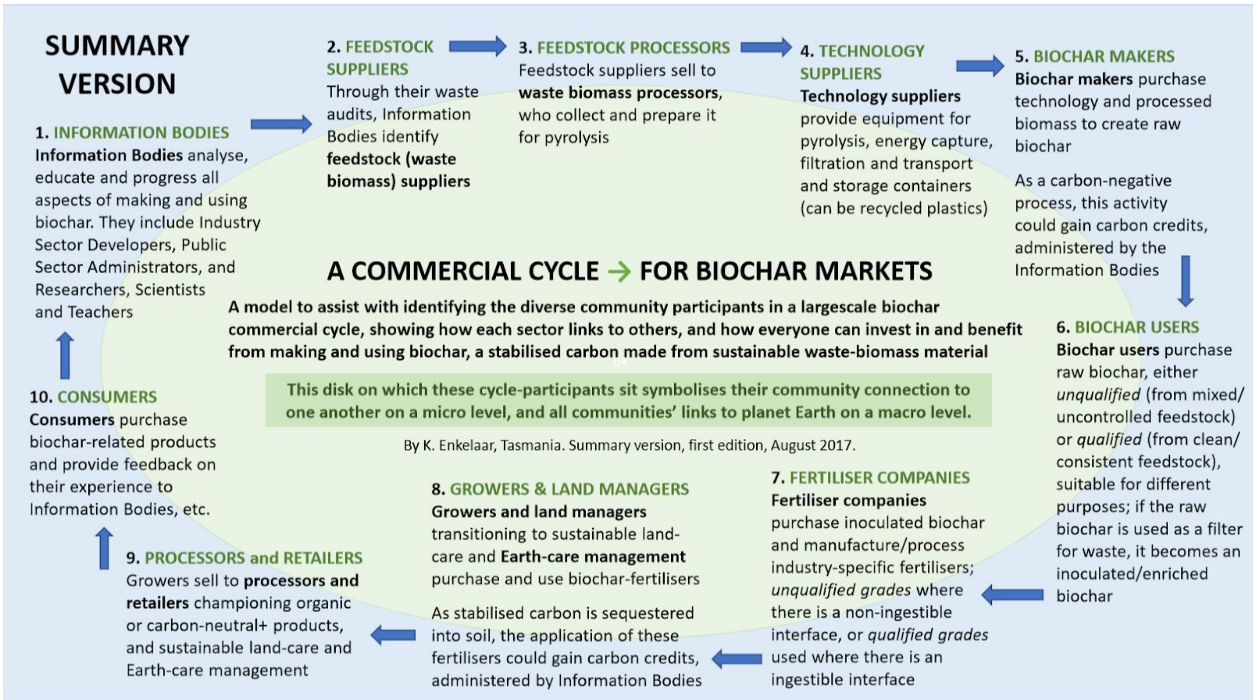
Source: ANZBI Conference

Earth Systems Nigel Murphy Interview



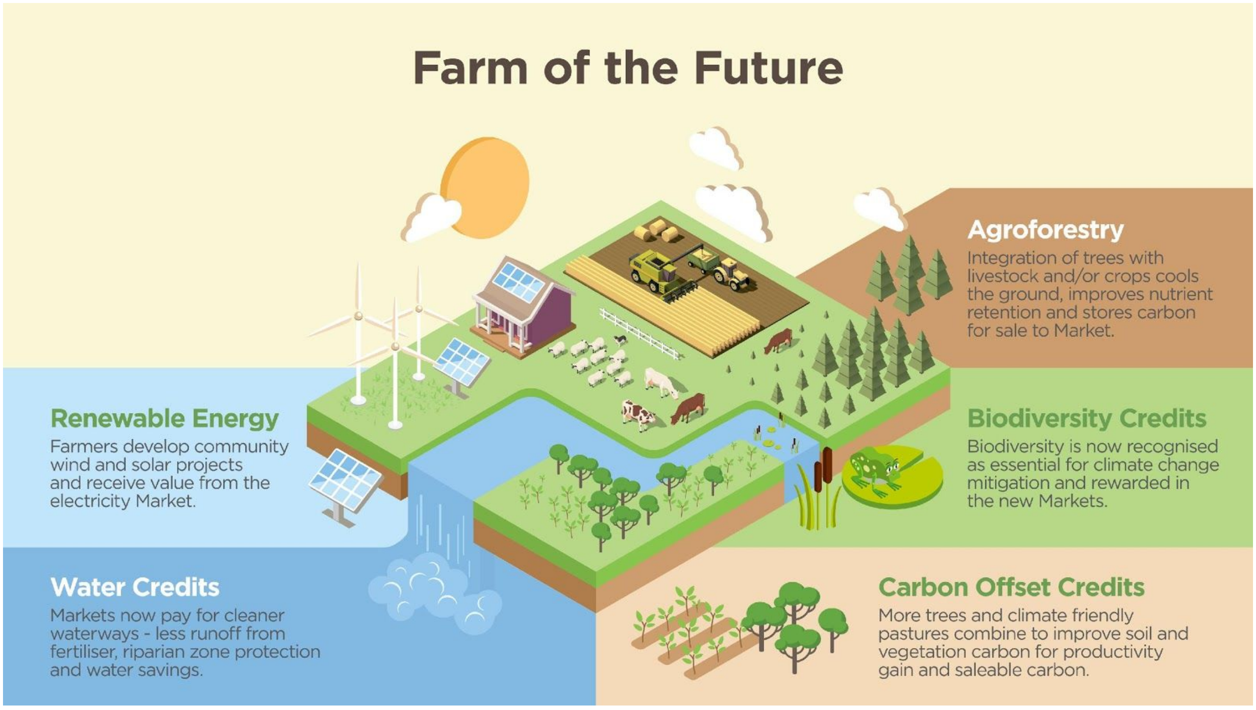
9.4 Appendix D: Relevant ANZBI Slides

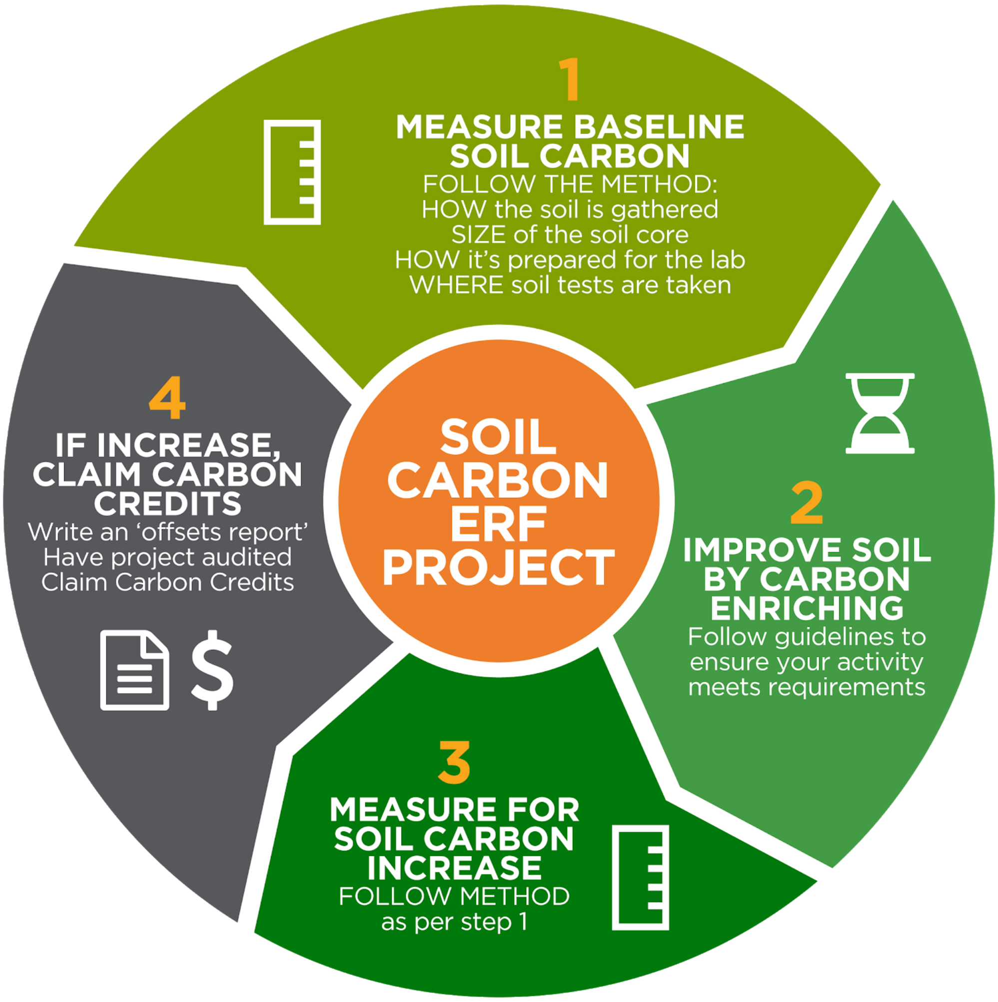
A Commercial Cycle → For Biochar Markets



Source: K. Enkelaar, Tasmania, Australia. First Edition, August 2017.

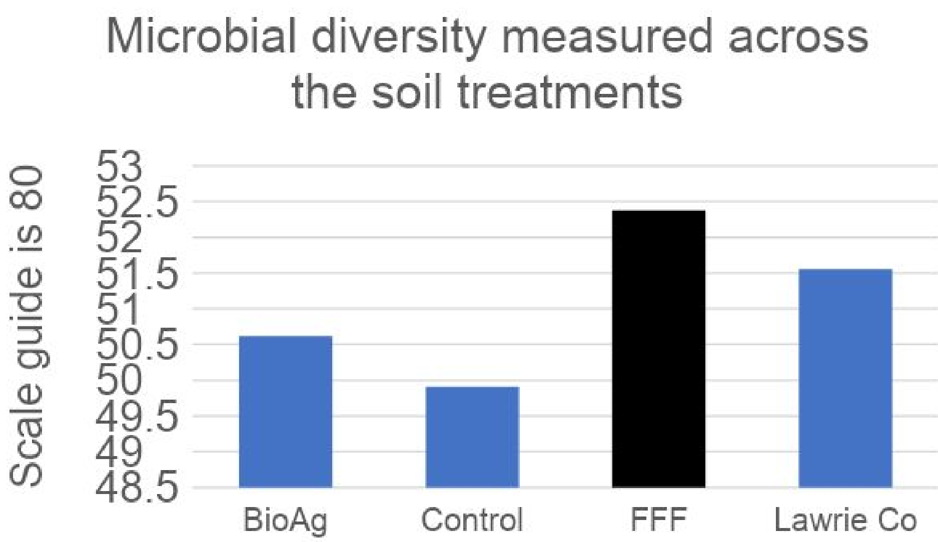
Carbon Farmers of Australia



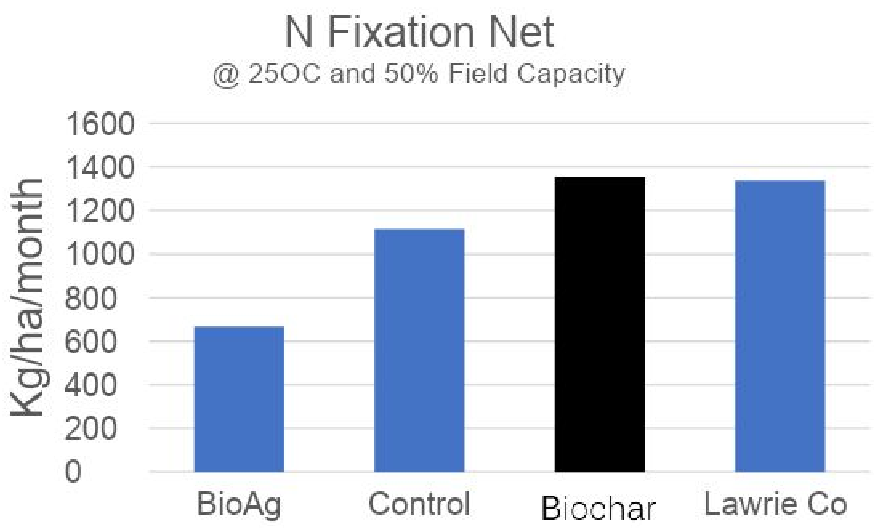


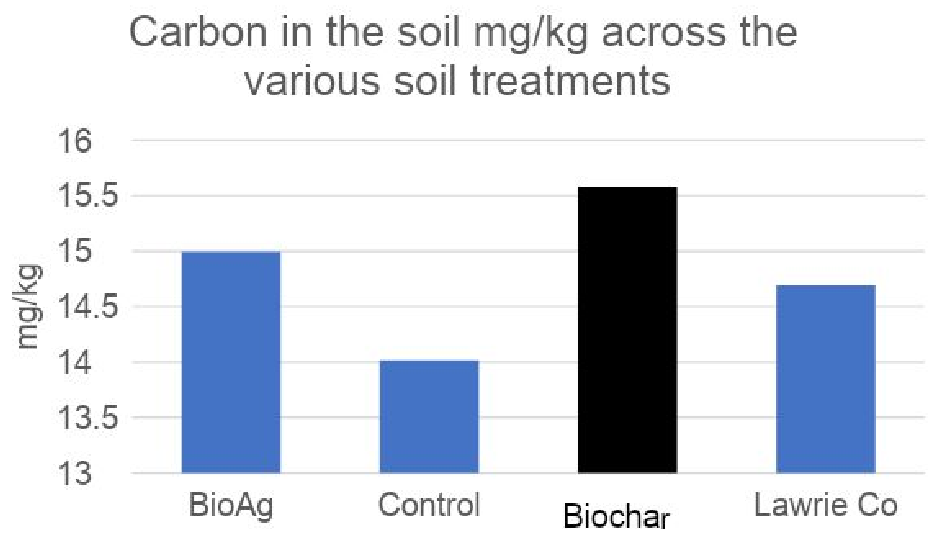
Source: Lousia Kiely

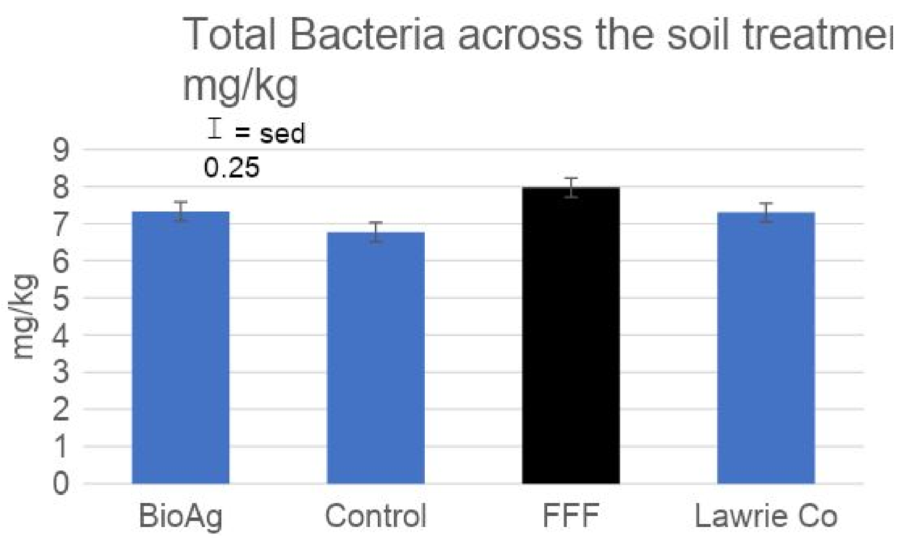
Melisa Rebbek



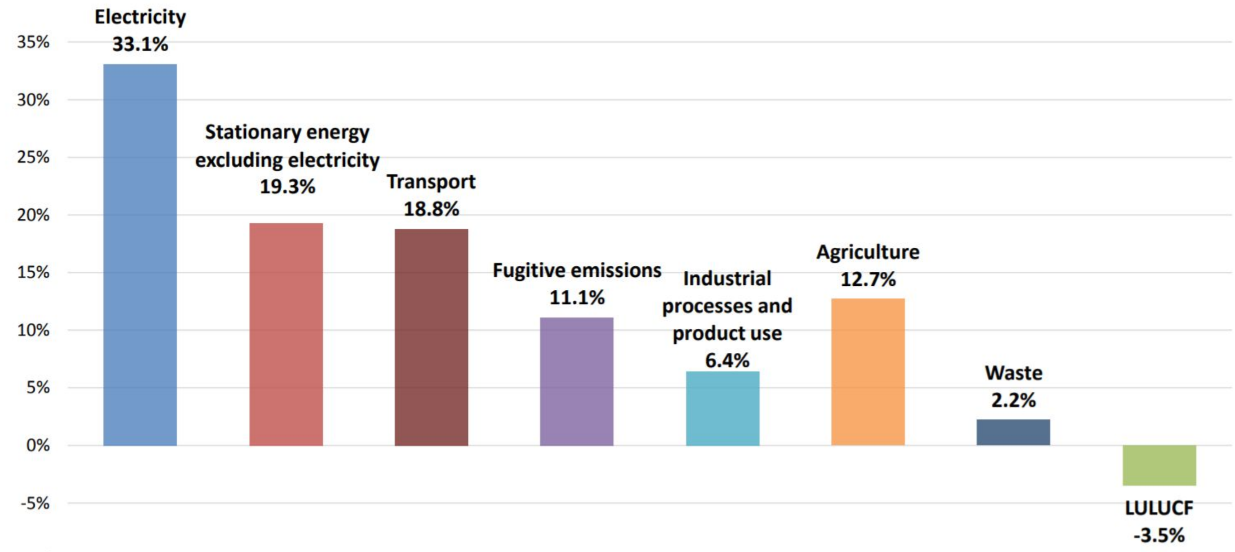
FFF=biochar


N Fixation Net
@ 25OC and 50% Field Capacity
Kg/ha/month
1600
1400
1200
1000
800
600
400
200
0
BioAg
Control
Biochar
Lawrie Co


Carbon in the soil mg/kg across the various soil treatments
mg/kg
16
15.5
15
14.5
14
13.5
13
BioAg
Control
Biochar
Lawrie Co

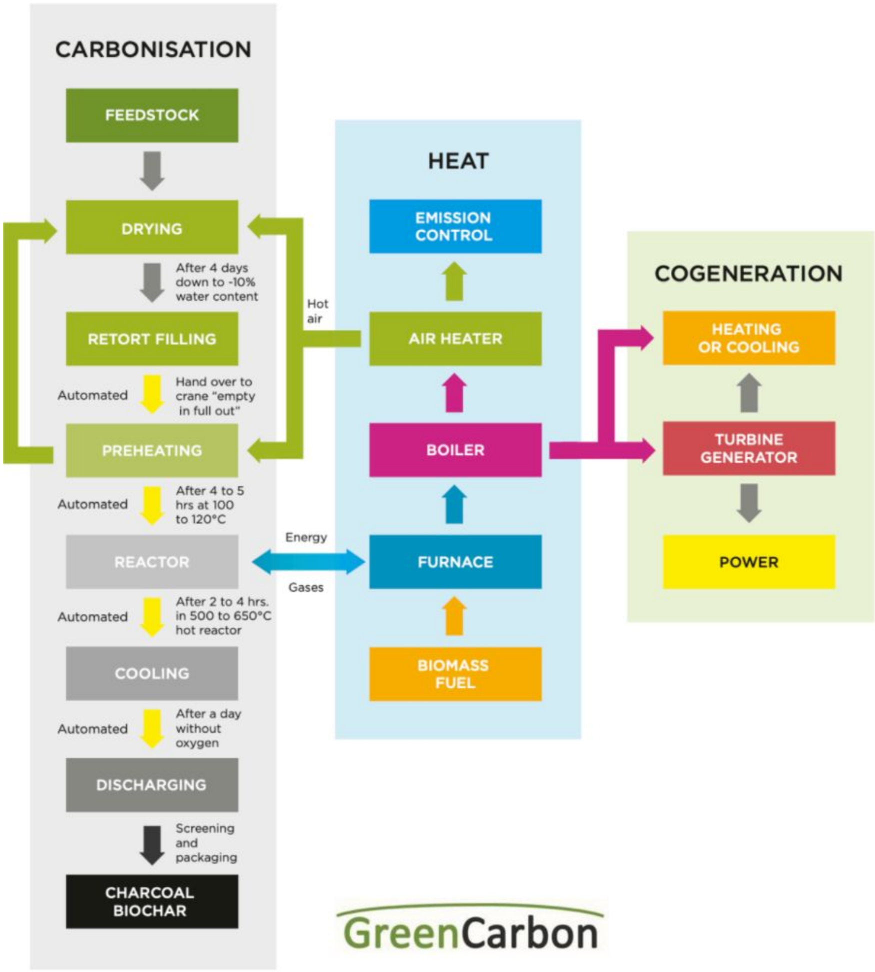

Total Bacteria across the soil treatme
mg/kg
= sed
0.25
mg/kg
9
8
7
6
5
4
3
2
1
0
BioAg
Control
FFF
Lawrie Co

FFF=biochar

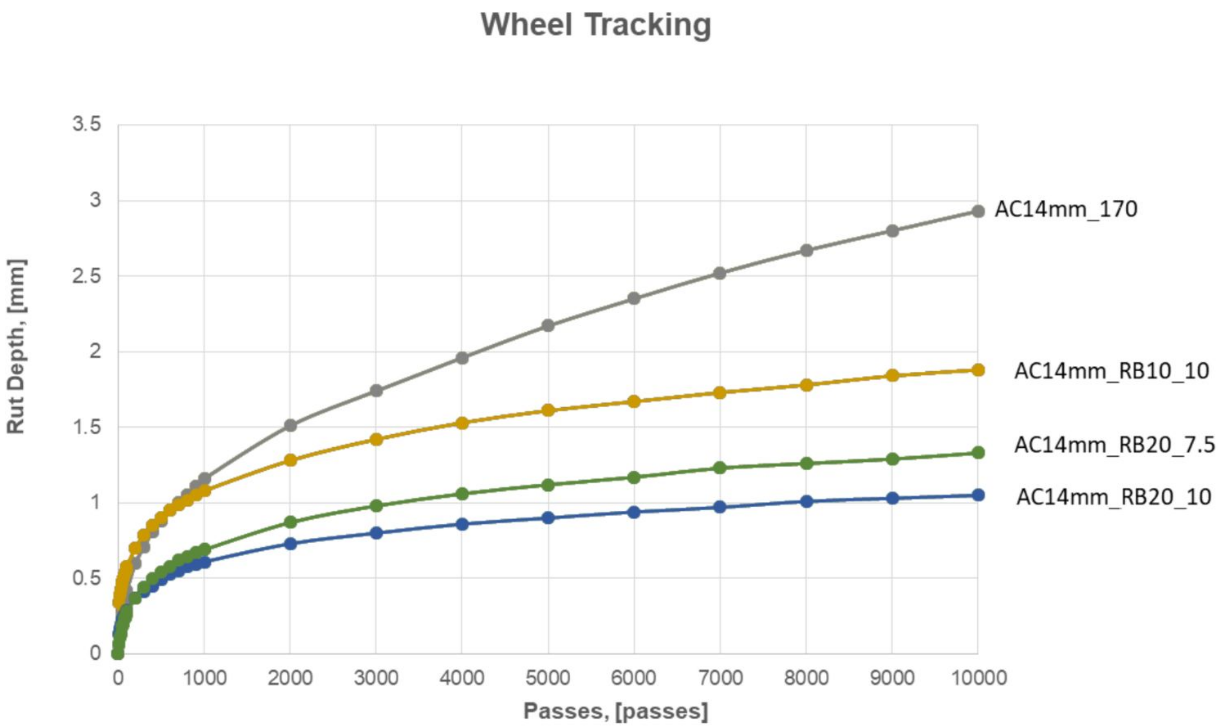


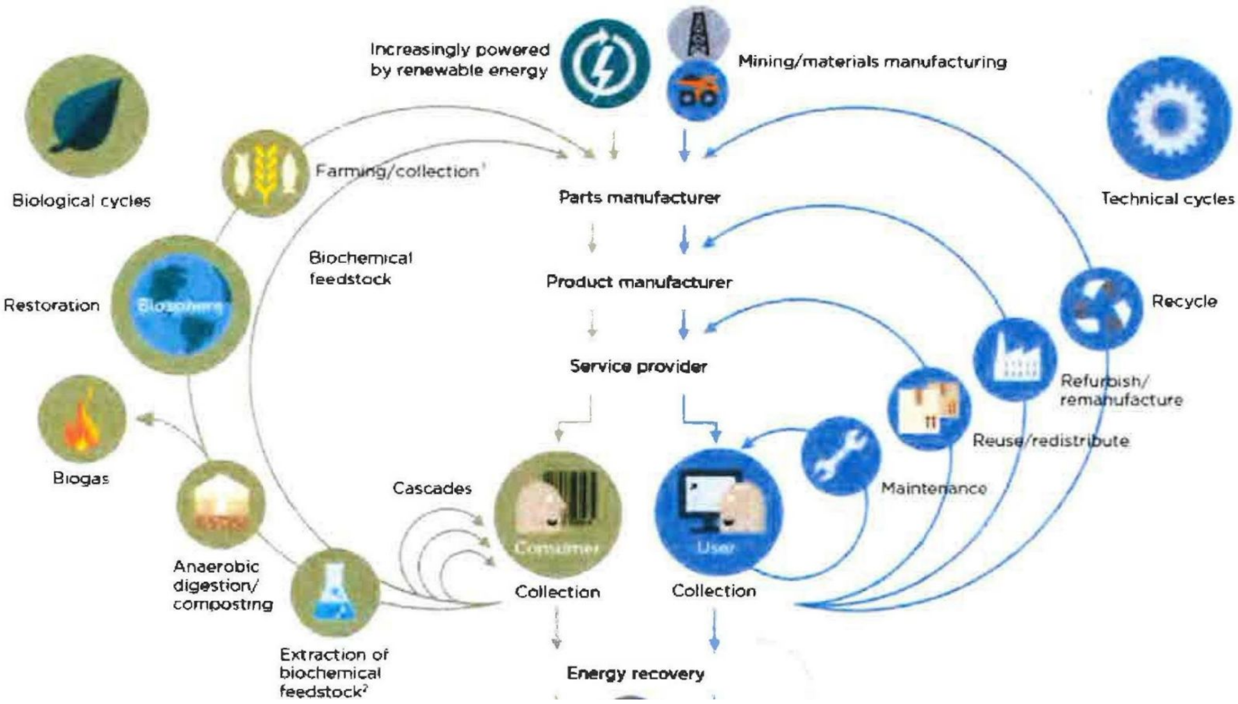
Source: Department of the Environment of Energy

Polytechnik Biomass Energy

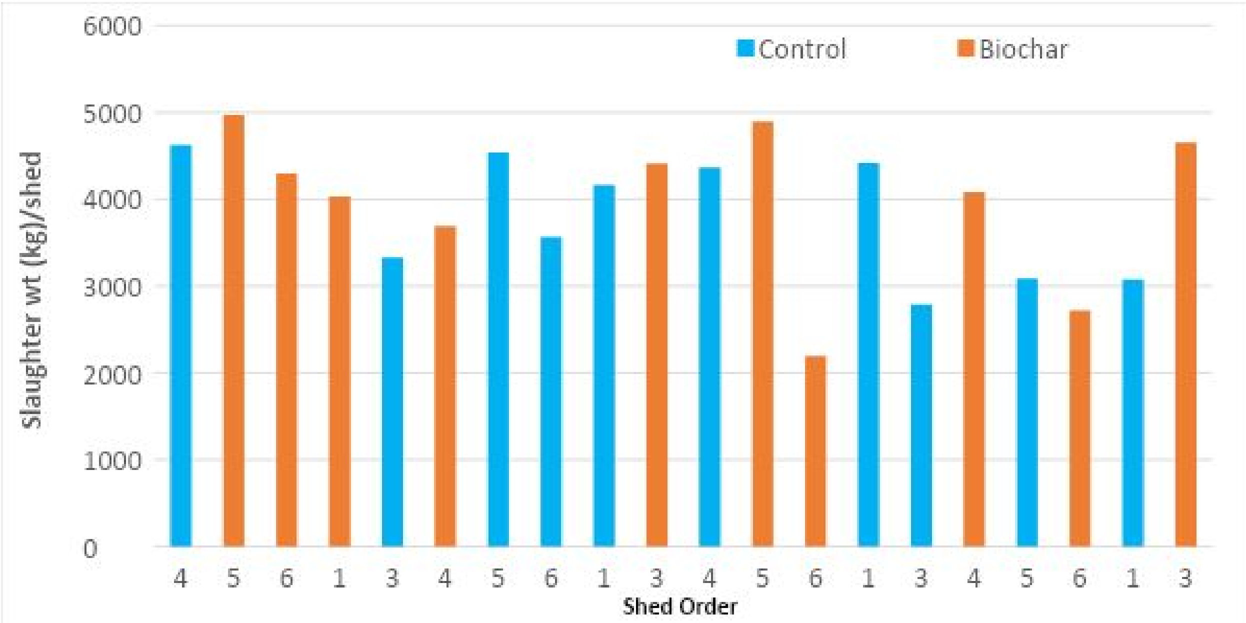


Rubberised Biochar used as Bitumen Additive



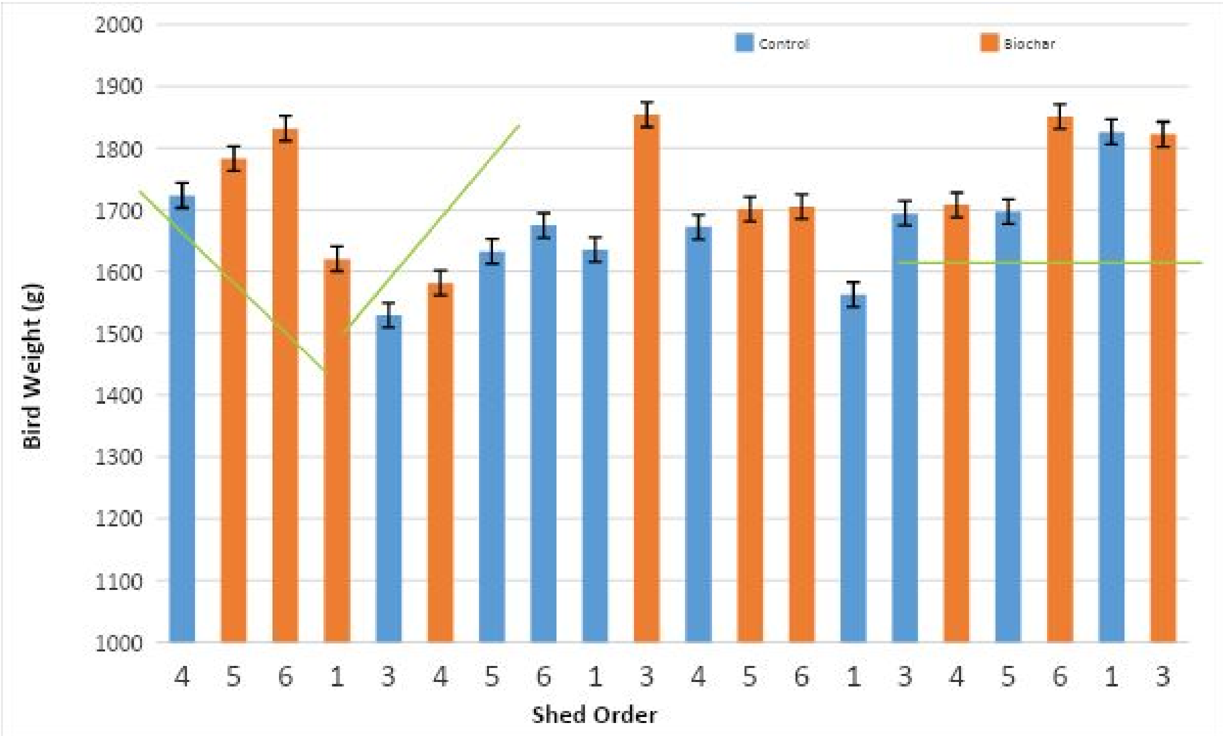


Bird Meat Weight at Slaughter (whole shed)



Variable shed conditions but biochar treatments higher slaughter wt (3794 kg vs 3996 kg= 5.3% increase in meat yield)

Average Bird Weight (100 birds at 43d)



Variable shed conditions but biochar treatments higher overall (1665g vs 1746g= 4.9% increase in bird weight)

9.5 Appendix E: Biochar Certification Process

One of the greatest impediments to biochar's market growth is a lack of knowledge, specifically among policy makers. When legislators are ill informed, they do not push enabling policies for biochar. This creates two connected issues. Without funds for research, biochar cannot be better understood. Biochar's benefits and best use practices cannot be explored, and research regarding the best way to market biochar cannot be done. This leads to the second issue, which is that the lack of knowledge leaves the market an uncertain and risky place to invest in. This means fewer companies can break out into the scene, so real market knowledge is even more limited. It stands to reason that educating regulators would be a good place to start give biochar a leg up in the market. Professor of soil biogeochemistry, Bruno Glaser remarks that politicians and stakeholders that are opposed to making enabling legislation for biochar "are mostly using this non-scientific publications for decision making. Most of it does not reflect state of the art scientific knowledge. Therefore I call it 'fake news'" (Glaser, 2019). It is imperative that the facts about biochar's benefits are made clear to politicians. A clear framework for a biochar certification system in Australia would give legislators the opportunity to dispel some of the myths about biochar and enable clear decision making around policies affecting biochar. A certification will only facilitate this process if it's done correctly, which is a complicated task.

The International Biochar Initiative gives some helpful standards that classify biochar's chemical and physical properties. First listed is carbon storage class shown in Figure 16 measured by quantity of organic carbon estimated to be mineralised for at least 100 years ((BC_{+100}).

Carbon storage classes	
5	$sBC_{+100} \geq 600g\ kg^{-1}$
4	$500g\ kg^{-1} \leq sBC_{+100} < 600g\ kg^{-1}$
3	$400g\ kg^{-1} \leq sBC_{+100} < 500g\ kg^{-1}$
2	$300g\ kg^{-1} \leq sBC_{+100} < 400g\ kg^{-1}$
1	$sBC_{+100} < 300g\ kg^{-1}$

Figure 16. Class of carbon storage for biochar depending on mineralization of carbon (International Biochar Initiative, 2018).

Biochar certification is impertive because it begins to give an idea of how sustainably produced a given char is. Since biochar is highly similar to charcoal, carbon black, and activated carbon, it is important to distinguish biochar from these products. The key difference in expert's opinions, such as Nigel Murphy, is that biochar is 'branded' as a green product. This means it is produced in a sustainable way: no deforestation, diversion of food products, or highly emissive production for the purpose of creating char. Not only does this mean biochar can be safely produced for years to come without negative impact on the environment, it also means it can benefit from policies enabling green products. However, carbon sequestration is only one part of a potential sustainability certification for biochar. It is also important to consider where the feedstock for the biochar is sourced. Ideally, it diverts a waste stream that would end up landfilled or incinerated, thereby avoiding emissions. If biomass is sourced from crops that could be feeding people, more emissions may be created in the farming process than are avoided. Lastly, the pyrolysis process itself should be relatively clean. If a given biochar sequesters some carbon, but pyrolyzing the biomass releases more carbon than is sequestered, the process is not sustainable. All of these factors should be taken into account in certifying biochar.

Another key piece of a certification is the fertilizer class and grade. Fertilizer class represents the ability of the macronutrients P, K, S, and Mg in a given biochar to satisfy the expected yield and nutrient removal demands of maize (International Biochar Initiative, 2018). Maize is the chosen reference, as it is one of the most widely grown crops across the globe. The classes are shown in Figure 17. This explains how much a given biochar should be spread per area to provide enough of a given nutrient for maize. For example, $K_{3t}S_{9t}$ means that 3 tonnes and 9 tonnes of biochar applied per hectare would provide enough potassium and sulfur, respectively. The fertilizer would be assigned class 2 since it can provide enough K and S, but does not provide enough P and Mg at the maximum considered dosage of 10 tonnes per hectare.

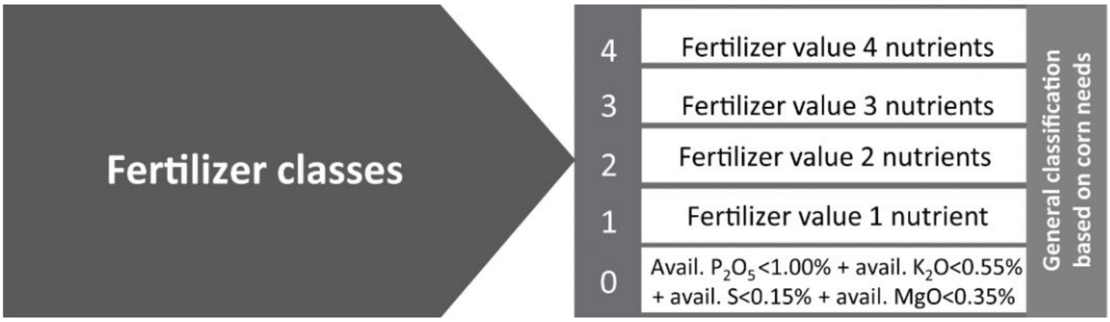


Figure 17. Fertilizer classes based on marcronutrient availability (International Biochar Initiative, 2018).

Fertilizer grade differs from fertilizer class, in that it represents the sheer mass of plant nutrients in the biochar per total weight, rather than their availability. It also tracks more nutrients: P, K, S, Mg, N and Ca. P, K, Ca, and Mg are given by their oxide forms, as is typical for commercial fertilizers. This is important information for end-users so they can consider application in contusion with other fertilizers with soil fertility in mind.

The next piece of the chemical certification is liming class. In other words, the ability of a given char to raise soil pH. Soil acidity can greatly limit plant growth, and many chars have the capacity to amend or mitigate the situation. Liming values are given as the proportion of liming affect that calcium carbonate would have ($CaCO_{3\text{-eq}}$). The classes are shown in Figure 18.

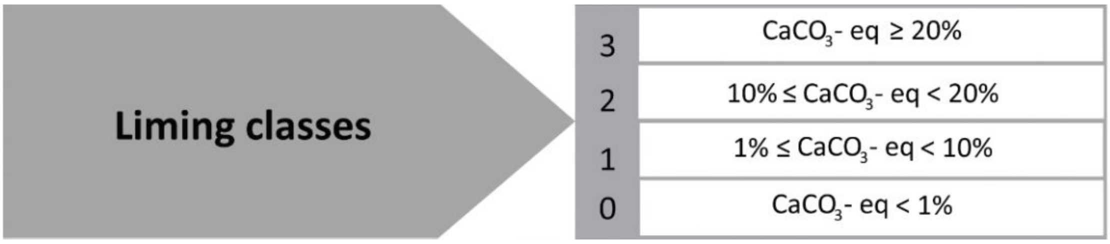


Figure 18. Liming classes of a based on alkalinity in terms of equivalent $CaCO_3$ content (International Biochar Initiative, 2018).

Part of the reason biochar is so useful for a variety of applications is its highly porous nature. Therefore, particle size class is another vital piece of the certification. Figure 19 provides a general classification for biochar depending on the proportions of various particle sizes. 'Lump' chars have more large pore sizes (>16mm), 'powders' have mostly smaller sizes (<2mm) and 'kernels' have sizes mostly in between. If there are mixes of wide ranging sizes, the char is 'blended.' Each type is better for different applications.

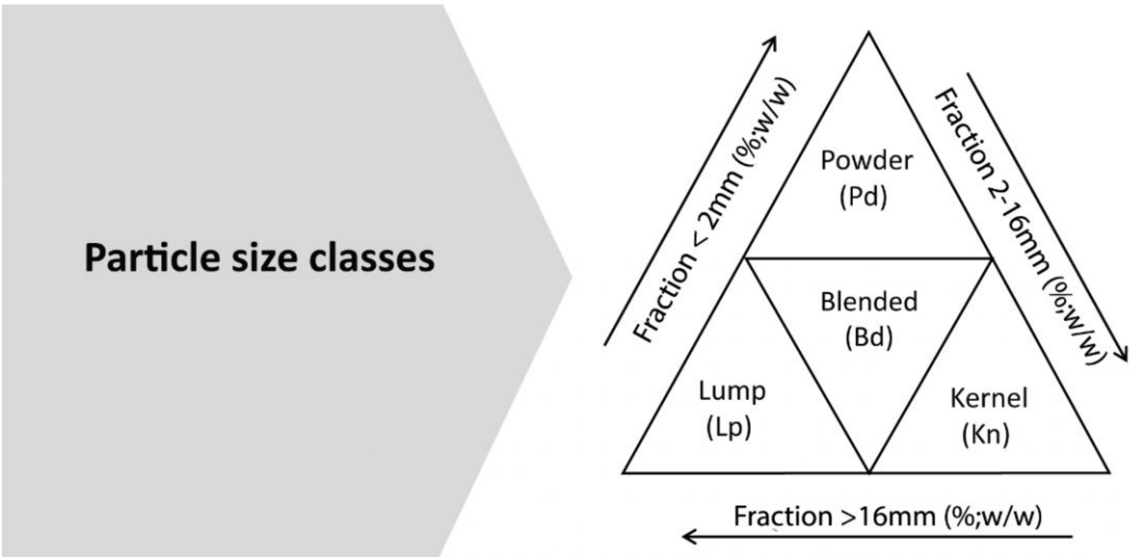


Figure 19. General biochar classification by particle sizes (International Biochar Initiative, 2018).

This idea can be used to further classify into coarse, fine, and medium variants of lumps and powders. This is illustrated in Figure 20.

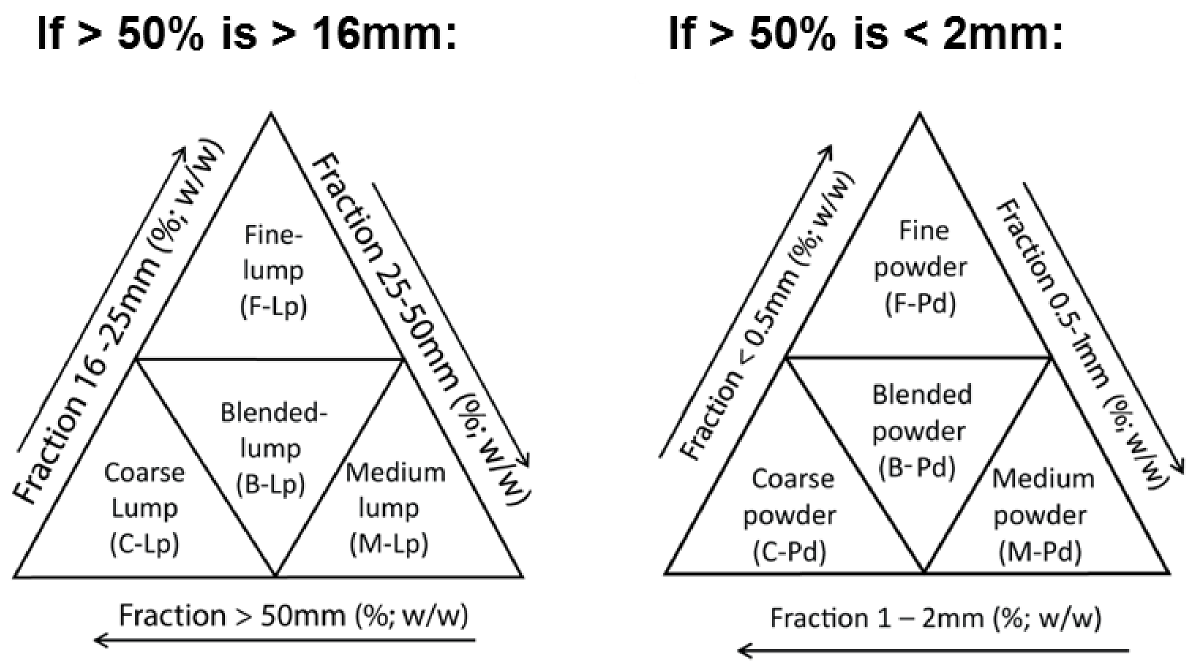


Figure 20. Specific breakdown of powder and lump pore sizes (International Biochar Initiative, 2018).

Similar to fertilizers, it is important that biochars containing toxic and dangerous contaminants do not have potential to cause harm if used for various applications. For example, in chars that will be used as a soil amendment, there should be limited enough leachate potential, so no harm can become of it. Toxic Chemical Leachate Potential (TCLP) is the recommended means of measuring this by the ANZBI (2017). The ANZBI recommends the method laid out by United States EPA to test the chars. Other dangerous compounds should meet the following requirements via the test method already standardised by the Australian government, AS 4454-2012. Allowable concentrations are shown in Table 7.

Table 7. Maximum concentrations of potentially harmful element to meet legal standards (ANZBI, 2017).

Parameter	Maximum Allowed Limit (Total Concentration) (mg/kg dry wt)
Arsenic	20
Cadmium	1
Chromium	100
Boron	100
Copper	150
Lead	150
Mercury	1
Selenium	5

Zinc	100

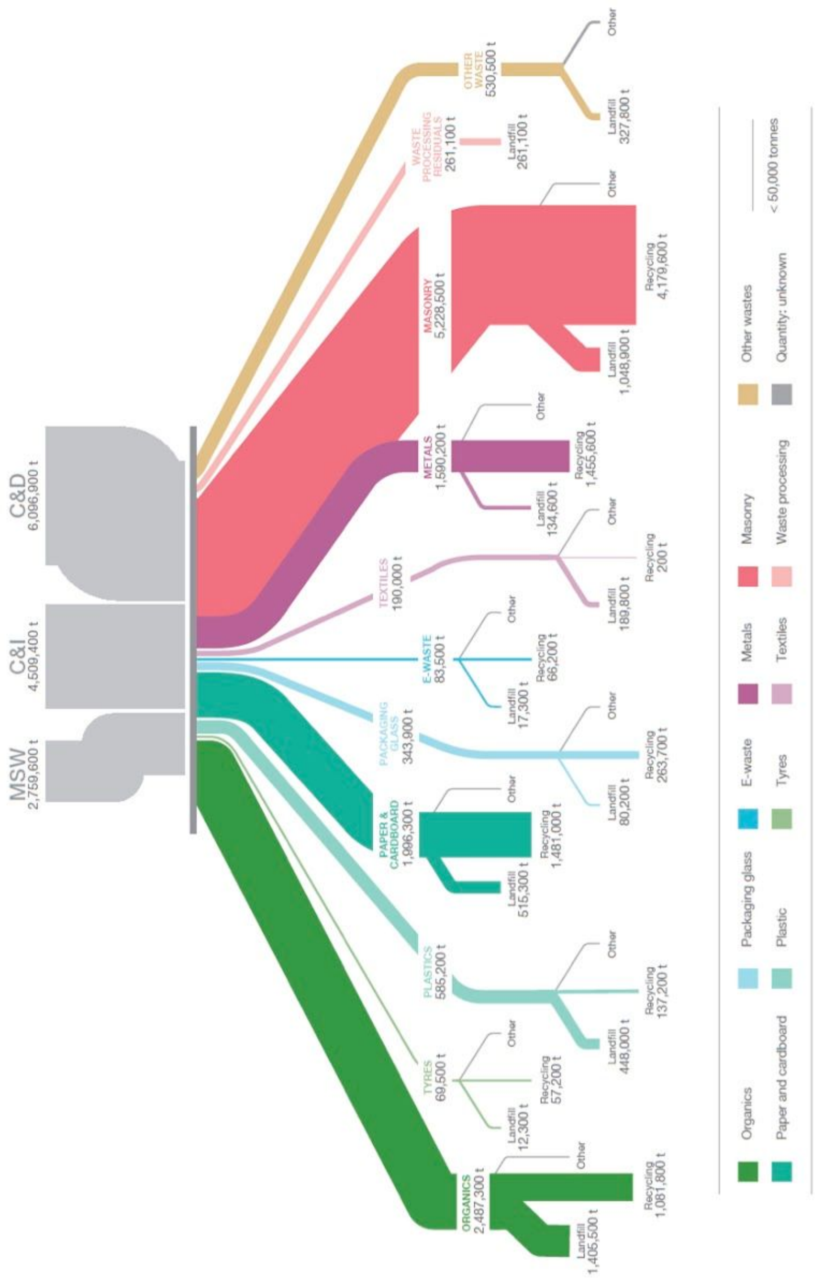
There are further dangerous organic \compounds that should also be considered and are shown in Table 8.

Table 8. Legal requirements for dangerous organic compounds in chars (ANZBI, 2017).

Parameter	Requirement	Units	Test Method/Requirement
Polycyclic Aromatic Hydrocarbons (PAHs), total (sum of 16 US EPA PAHs)	As per state EPA regulations applied for specific biomass amendments applied to soil	mg/kg (dry wt)	As per state EPA regulations applied for specific biomass amendments
Dioxins/Furans (PCDD/Fs)	As above	ng/kg WHO-TEQ (dry wt)	A As above
Polychlorinated Biphenyls (PCBs)	As above	mg/kg (dry wt)	As above

9.6 Appendix F: Relevant Diagrams about Waste Streams in Victoria

Figure 4: Waste flows in Victoria by material 2018/19



Source: Blue Environment (2019)

Figure 5: Summary of future waste scenarios

Intervention components	SCENARIO DEVELOPMENT					
	Out of Sorts	FOGO FOMO	Closing the Floodgates	Circular Stewards	Packaging Crackdown	High Energy
Recovery of dry recyclables	Medium Restricted materials and high residual	Low Restricted materials acceptance	Medium	Medium Value focus, fewer materials, higher residual	High Reduced throughput, reduced contamination	Low Restricted materials acceptance and throughput
CDS in Victoria	No	No	No	Yes	Yes Expanded to include all glass packaging	No
Energy from Waste	Low	High Accepts unsaleable recyclables and MSW	High	Low	Low	High
Organics separation	Medium	High Mandatory for councils (households) and food businesses	Medium C&I focus	Medium Household and C&I organics focus	High C&I focus	Medium C&I focus, mixed adoption by councils for households
Large reprocessing infrastructure	High Focus on plastics and glass	High Focus on organics	High Use of domestic recycled content increases	Medium Use of domestic recycled content increases	Medium Use of domestic recycled content increases	Medium
Small scale reprocessing	Medium Focus on priority waste streams	High Organics valorisation focus	Medium	High Expands significantly	Low Bio-based replacements for plastics	High Focus on priority waste streams
Export focus	Medium Unprocessed waste not accepted. Restricted materials and tonnage	Medium Unprocessed waste not accepted. With very restricted tonnage	Low Only clean, value-added inished products/ processed materials allowed for export	Medium For finished products and Refuse Derived Fuel. Low for unprocessed recyclate	Medium Unprocessed waste not accepted. Recyclate material quality improved	Low Due to quality issues

Source: adapted from Arup Recycling & Resource Recovery Infrastructure Analysis

Source: Infrastructure Victoria. (2019). *Recycling and Resource Recovery Infrastructure* .

9.7 Appendix G: Recarbonization of Global Soils Summary

Soil can play a powerful role in sequestering carbon. Soil carbon can remain safely locked away for thousands of years. Unfortunately the world's agricultural soils have lost between 25 to 75% of their original carbon supply. This happens because land degradation inhibis soils ability to maintain and store carbon. However, implementing soil management strategies can restore and build up soil's carbon storing abilities. This could have drastic positive impacts. The effects proper soil organic carbon (SOC)-centred sustainable soil management (SSM) practices could help offset some of the large amounts of emissions created in the agricultural industry.

> "SOC content is one of the most cost effective options for climate change adaptation and mitigation, and to combat desertification, land degradation and food insecurity."

The Recarbonization of Global Soils (RESOIL) is plan to remediate soils. Its goals are to prevent further SOC loss, increases SOC stocks, increase farmer's incomes, improve food security and nutrition, and mitigate climate change. They plan to achieve this in a few ways summarised in Figure 21.

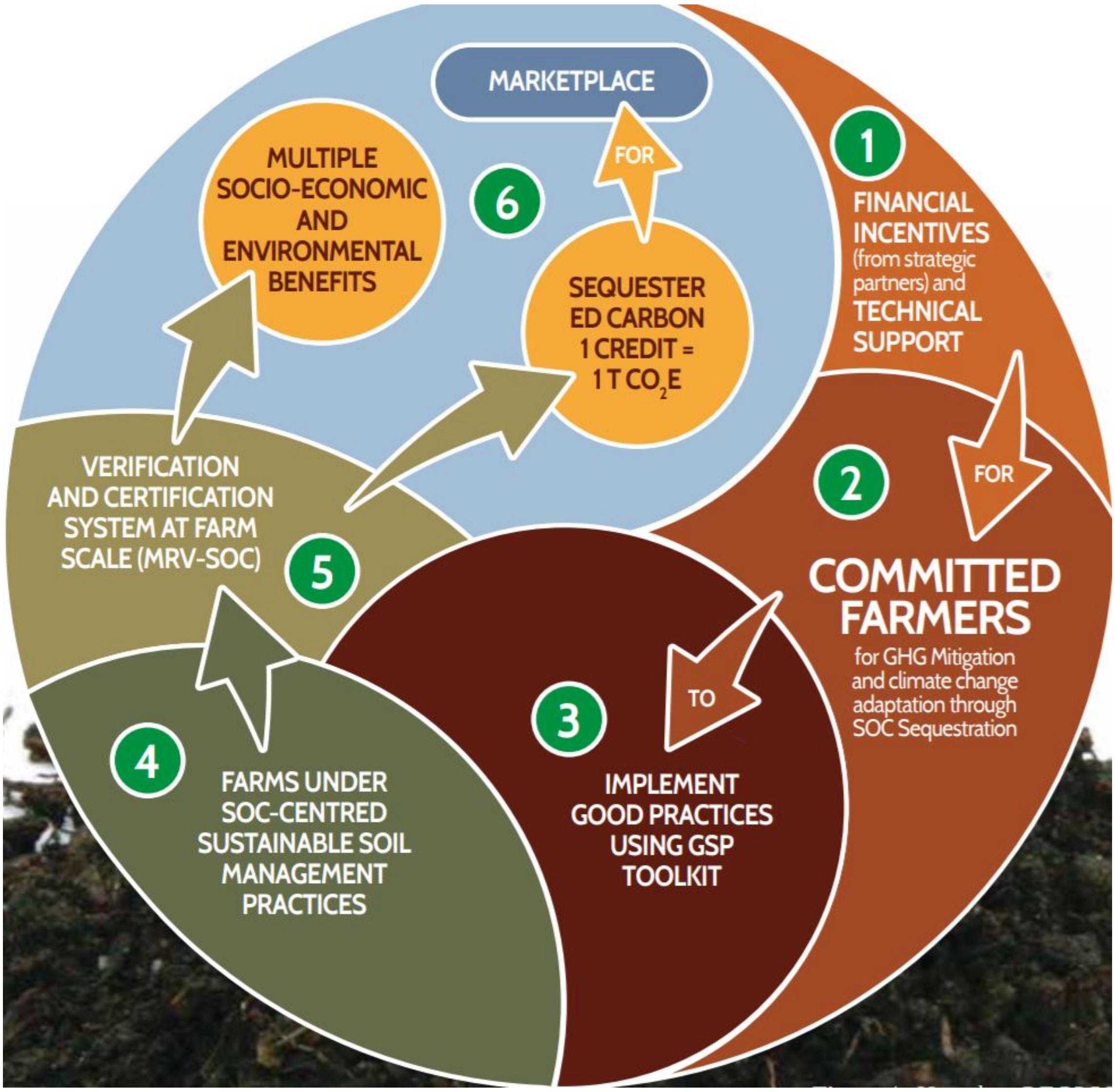


Figure 21. How RECSOIL creates benefits.