Biochar's Potential in Australian Farming Systems

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Executive Summary

The global Biochar industry is rapidly expanding as technological advances, environmental pressures, and market demand positions biochar as a valuable tool for carbon sequestration, sustainable energy generation, and soil enhancement. This report investigates how farmers are using biochar to improve soil structure, increase animal performance, increase water-holding capacity, enhance nutrient efficiency, and reduce fertiliser dependency.

For Australian farmers, the growth in the biochar industry creates opportunities to reduce input costs, improve soil resilience, and diversify income streams while contributing to sustainable, low-carbon agriculture. This report examines three viable farmer-led biochar production models: medium-scale centralised, small-scale mobile, and medium-scale co-operative, and highlights the practical benefits, challenges, and adoption pathways.

Medium-scale centralised systems are increasingly preferred for commercial biochar production due to their balance of scale, efficiency, and revenue diversification. These fixed pyrolysis plants typically process 3,000 – 9,000 tonnes of feedstock annually and generate income through biochar sales, energy production, and carbon credits. Global and local case studies, including Sitos Group (USA) and Holla Fresh (SA), demonstrate that reliable feedstock streams, strategic partnerships, and appropriate technology can produce strong financial and environmental outcomes. Challenges include high capital costs, maintaining consistent feedstock quality, and navigating carbon credit certification.

Small-scale mobile production – the use of basic equipment provides a low-cost entry point for practical, on-farm biochar production. This model offers flexibility, portability, and minimal financial risk, but is constrained by labour demands, variable product quality, and relatively low output volumes.

Medium-scale co-operative models provide another pathway, exemplified by Frantoio Del Grevepesa in Italy. Farmer co-ops can leverage shared feedstock, centralised infrastructure, and multiple revenue streams from energy, biochar, and carbon credits. Biochar produced can be returned to member farms, creating circular economy benefits, spreading risk, and improving soil health across the group.

Across all models, success depends on securing consistent feedstock, optimising technology selection, developing multiple revenue streams, and building strategic relationships. As the global momentum toward low-carbon, regenerative agriculture grows, biochar provides Australian farmers with a practical, profitable, and environmentally sustainable pathway to enhance soil resilience, manage biomass sustainably, and participate in emerging carbon markets.

Keywords: biochar, cropping, grain, arable, dryland, change management

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Foreword

Growing up on a mixed broadacre farming property (cereal grains and sheep) on South Australia's Murray Plains, where annual rainfall was supposed to be 300mm, though it erratically bounced around this figure, I struggled to be motivated to return straight home from school into this challenging environment. Instead, I chose the path of earning an Economics degree, then moved into grain marketing and business consulting for farmers for 6 years. When the call from the family farm grew stronger, I returned to the family business in 2008, where, by this stage, we also owned additional property in higher rainfall zones. Over the next 12 years we expanded our business to include a large lamb feedlot, increased cropping operations and marketing direct to the consumer. Deaths within the family, followed later by succession adjustments between my brother and I, led me to currently farm solely alongside my wife, Kimberley, and children at our property near Angaston in the Barossa Valley of SA.

When I initially applied for my Nuffield Scholarship, I was intending to research what logistical improvements could be made to increase the speed of operations of agricultural drones. We had been using a drone for broadacre spraying on our farm, and the logistics of moving sites with all the associated equipment were limiting operations. Although this topic certainly had merit, after attending the CSC (Contemporary Scholars Conference) in Brazil (where I was exposed to larger global trends) I started to question if I could make better use of my Nuffield opportunity.

Biochar had always been in the back of my mind, having conducted small trials on our farm, but I really didn't know that much about it. Several months after the CSC, I was on tour with our GFP group in Denmark, and we happened to be there when the Danish Government introduced a carbon tax on livestock emissions, the first in the world to tax agriculture. This "Green Tripartite Agreement" aims to reduce the total of greenhouse gas emissions by 2.6 million tonnes by 2030. What really sparked my interest was that the Danish Government has identified biochar as a central pillar in achieving its climate goals and is willing to make a significant investment in it. Around 10 billion Danish Krone (DKK) (around AU$2.4 billion), which is approximately 25% of the total funds raised from their emissions tax, will be used for pyrolysis technology and boosting the adoption of biochar in agriculture to sequester carbon and improve soil health. The Danish agreement, and biochar's role within it, is seen by many as an inspirational model for climate leadership across Europe. If this model does extend through Europe, it is likely to have implications for Australian farmers.

Locally, when we had our own branded meat company, I experienced first-hand the changing consumer demand for nature-friendly and reduced chemical inputs in Australian farming systems The trend is global, and when combined with the rising costs and supply issues recently experienced with artificial inputs (such as fertilizers, chemicals), it made sound business sense to look for alternative models: Biochar appeared to tick many of the boxes.

Although its basis is relatively simple, biochar has complexities across production, application methods and economics. I wanted to investigate if and how Australian farmers could successfully incorporate biochar into their businesses to get ahead of these approaching global trends.

Countries I visited during my Nuffield travels included Brazil, Indonesia, France, Denmark, USA, Chile, New Zealand, Italy, Japan and regional Australia. In many countries, I saw how biochar can have an impact on both community and environment across range of production outputs.

Acknowledgments

I would firstly acknowledge the love and support of my family. My wife Kimberley, children Ava, Charli and Archie have all been my greatest cheerleaders and without them none of this would have been possible. Thank you with all my heart.

Figure 1. Charli, Paul, Archie, Kimberley and Ava McGorman (Source: Author)

Thank you to my generous sponsor, Grains Research and Development Corporation (GRDC), not just for your financial support, but for your willingness to embrace my late change of topic. The GRDC are leading the way for Australian grain growers through their research, development and extension and I am proud of my association with them.

To the Nuffield Australia staff, in particular Jodie, Tessa and Carol, thank you for your great communication and support through my whole journey. Your collective leadership helped shape my wonderful experience.

Thank you to Melissa Rebbeck, Chair of Australia and New Zealand Biochar Group for sharing your passion and enthusiasm for biochar with me. Your energy is very contagious!

I would like to acknowledge all the individuals and businesses that welcomed me on my Nuffield adventure. Your openness and generous sharing of knowledge was invaluable.

A final thankyou to my new lifelong friends gained travelling on my GFP. You have been fantastic support and encouragement to me which is appreciated.

Abbreviations

ACCU	Australian Carbon Credit Unit
ANZBIG	Australia and New Zealand Biochar Industry Group
AU	Australian Dollar
BECCS	Bioenergy Carbon Capture and Storage
BiCRS	Biomass Carbon Removal and Storage
CDR	Carbon Dioxide Removal
CEC	Cation Exchange Capacity
CO2	Carbon Dioxide
CSC	Contemporary Scholars Conference
DAC	Direct Air Capture
EQIP	Environmental Quality Incentive Program
ESG	Environmental, Social and Governance
FDA	Food and Drug Administration
GFP	Global Focus Program
Ha	Hectare
IBI	International Biochar Initiative
MRV	Monitoring, Reporting and Verification
N	Nitrogen
NRCS	National Resource Conservation Service
Q2	Second quarter of financial year
RA	Regenerative Agriculture
SA	South Australia
TSP	Technical Service Provider
USBI	US Biochar Initiative
USDA	US Departure of Agriculture

Objectives

The objective of my report is to investigate whether and why Australian farmers should use and produce biochar, and, if so, how they should go about it.

My aim is to answer the following questions:

- Why is there a resurgence in biochar?
- How can Australian farmers use and benefit from biochar in their businesses?
- What business models are there for Australian farmers to successfully establish their own biochar production plants?

Introduction

What is Biochar?

Biochar is a charcoal-like material produced when organic material, such as wood, agricultural waste, or sewage waste, is burned in a low-oxygen environment, a process called pyrolysis. Through this process the majority of carbon dioxide that would otherwise have been emitted into the atmosphere via natural decay is captured and stored in the biochar.

As biochar is a porous carbon material with a substantial surface area, it can adsorb and retain significant amounts of nutrients and water molecules. With its "honeycomb/coral-like" structure, biochar can provide a home for all a wide range of microorganisms and biota. Biochar's variable cation and anion exchange capacity attracts excess nitrogen and other nutrients otherwise lost or leached away. This is stored and available to plants when called upon.

Key physical characteristics of Biochar are:

- black in colour
- lightweight
- highly porous
- very high surface area
- insoluble in water and most organic solvents
- high carbon content (around 70% depending on the production process)
- potentially high CEC (cation exchange capacity) depending on the production process

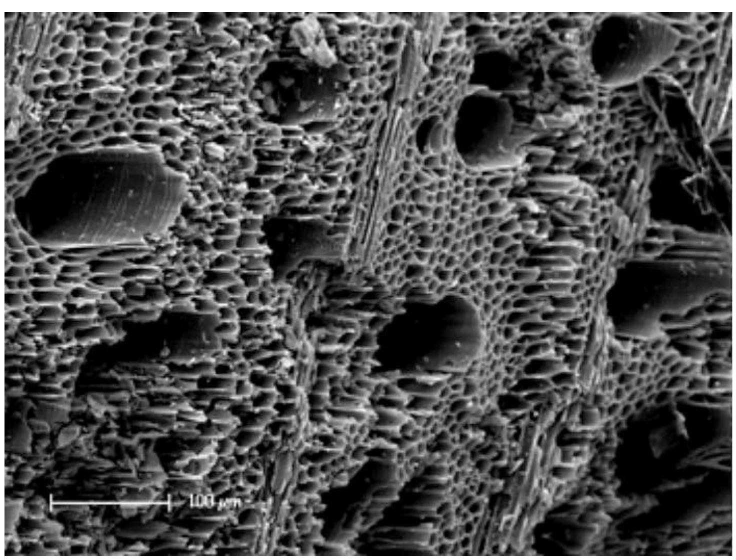

Figure 2. Biochar under a microscope (Source: Brownsort in James, 2016)

Figure 3. Biochar (Source: Author)

Biochar is found naturally around the world as a result of vegetation fires. It has been used by humans for agricultural purposes for over 2,000 years by the indigenous Amazonians of South America, who are credited for being the first to take an organic material, set it alight in large pits dug into the ground and let it smoulder away. This method of burning in a low-oxygen environment (the original form of pyrolysis) captured and stored carbon dioxide and resulted in the creation of the nutrient-rich "Terra Preta" (black earth) soils of the Amazon.

Figure 4. Terra Preta soils in the Amazon (Source: image adapted from Glaser et al., 2001)

Historically, jungle soils have been very unproductive with the high rainfall leaching away nutrients, however with the inclusion of biochar, these soils were improved to be able to sustain annual cultivation of crops, thereby enabling large communities to develop in the same location.

Although these traditional production methods (which are still used today in many countries) have been successful over the years, they have also had negative consequences, with excessive smoke creating health issues and inefficient conversion to stable carbon. Recent advancements in biochar production build on these traditional methods and improved them through utilizing closed systems of pyrolysis that burn at a high temperature with limited oxygen which capture most of the emissions. The emissions, which had previously been partially released back into the atmosphere, are now used to fuel the closed system or broken down into less harmful elements (see Diagram 1).

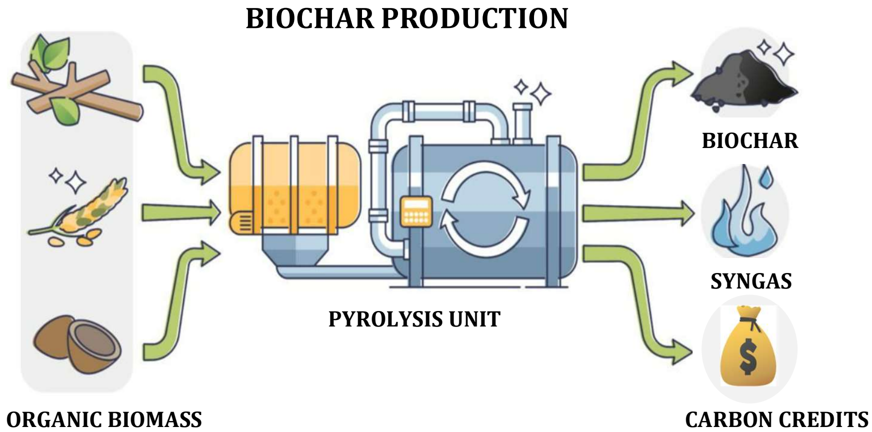

Diagram 1. Pyrolysis of Biochar (Source: Forliance, 2022)

In modern pyrolysis systems, organic feedstock such as wood, straw, and almond hulls are fed into the unit at temperatures between 650 and 800 degrees Celsius in a low-oxygen environment. At these temperatures, thermal breakdown of the organic biomass material continuously fed into the machine occurs, converting it into biochar. This biochar permanently stores around 50% (will vary depending on the production method) of the CO_2 of the initial organic feedstock.

Syngas is released from the biomass during the pyrolysis process and is captured to be converted into energy for heating, or, as a less efficient but still beneficial approach, converted to electrical power. Some of this energy can be used to keep powering the pyrolysis unit, enabling the machine to be self-sustaining once initial start-up has occurred. Energy can also be used to run pre-driers and chippers to reduce the feedstock to an ideal moisture level below 20% and to achieve a uniform particle size prior to entering the pyrolysis unit. This process of energy creation enables the remaining 50% CO_2 from the original feedstock to have a useful life before it is returned to the atmosphere (see Diagram 2. for an illustration of the Carbon Cycle versus the Biochar Cycle).

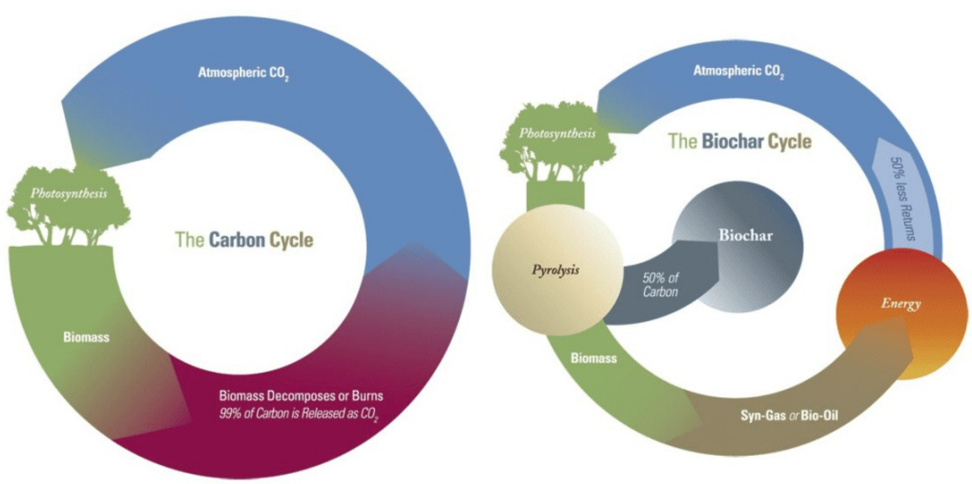

Diagram 2. The Carbon and Biochar Cycles (Source: McLaughlin & Pyle, 2016)

The Resurgence of Biochar

The production and use of biochar has been around for thousands of years with linkages to many indigenous cultures from around the world, not just the Amazonians. There has been steady growth in the industry since the 1960's, however it hasn't been until the past two decades that the biochar industry has really started to develop.

Zion Market Research has published a research report titled "Biochar Market Analysis: Global Industry Perspective, Comprehensive Analysis and Forecast, 2024 - 2032". In 2023, this report valued the global biochar market at around US$862.37 million and estimated that by 2032 it will grow at an annual rate of 13.84% to reach US$1,72.8 million. There is significant variance between research publications, however the positive growth trend is consistent. Key drivers of this growth both domestically and internationally are:

Improved Production Methods to Produce at Scale

There is no doubt that the technological advancements made in production methods has boosted the supply of biochar into the market. With more supply, there has been more of a marketing effort by manufacturers to sell biochar.

Kon-Tiki kilns (and variations of them) have evolved to be more user friendly and efficient and remain well suited to small-scale production such as home gardeners and small operators whose sole aim is to produce a limited supply of biochar.

Figure 5. Takachar's trailer-mounted pyrolysis unit (Source: Author)

There has been a rise in mobile units worldwide, such as curtain air burners and mobile pyrolysis machines. Rod Kux and his team at Takachar, near San Francisco, USA (Figure 4), with headquarters in India, are designing and building lightweight trailer-mounted pyrolysis units that can be towed to where the feedstock is located. This decentralized method has advantages in that it suits small or remote feedstock locations and can be accredited to generate carbon credits. Takachar intends to market these units (which are nearing the completion of their trial stage) to regional communities in India and Kenya where farming is on a smaller scale where and communities can look at shared-ownership models. Potential other markets are in the US forestry industry for bushfire reduction services removal of waste wood).

Significant growth in the number of manufacturers and the quality of the scale of commercial pyrolysis units has impacted on the amount of biochar produced. Commercial pyrolysis machines with a throughput of around 1,000kg/hr of dry matter are today commonplace in the market. Sitos Group in California has been operating a trial plant for several years and is now in the final stages of building the first of three pyrolysis units, which, once fully operational, will be capable of producing 8,000 tonnes of dry biochar per year. This is a common approach among larger operators in the industry, where they use multiple pyrolysis machines linked together, not just one massive unit.

Figure 6. Mayo Ryan from Sitos Group and Paul McGorman (Source: Author)

With technological advancements in pyrolysis units, such as improved control of heat dispersion, better conversion ratios, MRV (Monitoring, Reporting and Verification) tools, and improved capture and utilisation of heat energy, high-quality, fit-for-purpose, consistent biochar is now possible to produce at scale. The consistency in quality is helping to change some earlier variability that had previously resulted in inconsistent agricultural returns. Not only is better quality biochar being produced in these new pyrolysis units, but biochar producers are also now able to earn multiple income streams through biochar sales, the utilisation of the heat energy (either using the power generated themselves or selling excess power to the grid), and the generation of carbon credits.

Pyrolysis units are being designed and built right around the world, with several large local manufacturers in Australia (examples are Metamorf Engineering, Rainbow Bee Eater, Pyrocal and CPMTP (Carbon Powered Mineral Technology and Products). China, due to its low production costs and large-scale manufacturing capabilities, is a major manufacturer, with pyrolysis designers from around the world choosing China as their preferred location to build. As more pyrolysis units are built around the world, the cost of each unit will go down, according to Morten Heick, Secretary General of Pyrolyse Danmark, thereby reducing the initial capital outlay for biochar project developers. This will lead to more new biochar projects going from design to production, continuing to help grow the industry.

Carbon Credits

Carbon credits have been and will continue to be a major driver of the growth in the global biochar industry, as large corporations strive to offset their emissions. Carbon credits can provide a significant revenue stream for biochar producers, enabling biochar production to become economically viable and attract significant private investment.

Producers of biochar are creating durable carbon credits via their pyrolysis process at an average rate of 2.0 to 2.5t CO_2 equivalent sequestered per 1 tonne of biochar produced. Determinants of individual conversion rates include, but are not limited to, the type of feedstock, Lifecycle Assessments (which accounts for all carbon costs such as freight (feedstock and end product) and power used, the type of pyrolysis units and MRV (Measurement, Reporting and Verification) ability.

An example is a biochar producer with a medium-sized centralised pyrolysis unit making 1,000t/year of biochar. With a conversion rate of 2.3t/C02e, this will generate 2,300 carbon credits per year to sell. At the current market price (at the time of writing this report) of AU$240/t CO_2e (US$155/t CO_2e), this equates to a potential revenue from carbon credits of AU$552,000 per year. This can make biochar production very lucrative when revenue is also gained from the sale of physical biochar and value of the energy produced (either through cost-savings made or energy offtake agreements).

To earn voluntary carbon credits from biochar, producers must meet standards from global registries such as Puro.earth (owned by Nasdaq), Verra and Isometric. Each registry has slightly different standards which will suit different situations. Once durable (meaning permanence / stores carbon from the atmosphere for 100+ years) carbon credits have been listed of the registries, global corporations are able to purchase carbon credits to help meet their own ESG goals. Companies such as Microsoft, Google, Shopify and H&M have been making significant purchases in the past few years, boosting demand for biochar carbon credits. The durability of biochar as an effective CDR (Carbon Dioxide Removal) tool is a major reason why these corporations are looking towards biochar and why biochar carbon credits accounted for 89.4% of the total 116,800 tonnes of carbon credits delivered in the second Quarter of 2025 (Sylvera, 2025). Corporations such as JP Morgan Chase are also not just only buying biochar carbon credits, they are also directly investing in biochar projects as part of their climate action strategies, helping the industry to rapidly expand.

There are economies of scale with production required to justify the cost of producing carbon credits. This has left the large industrial scale operations to effectively be the only ones able to produce carbon credits, as the costs of meeting the standards are too high to justify for small to medium operators. In the past three years there have been multiple announcements of large-scale biochar CDR projects, however many of these have failed to launch or experienced significant time delays as project developers encounter the challenges of turning what looked an attractive investment on paper into a working operation. Sometimes the theory doesn't match reality.

The companies that have pushed through the establishment challenges are now releasing large volumes of biochar onto the market, and for them to be able to claim their carbon credits, the physical biochar needs to be introduced into a "matrix" (such as soil, as an agricultural input, or as a non-combustible building material). With soil and agricultural input (compost) the most common, this has been a win for farmers as biochar availability has increased and cost has gone down.

Increased Scientific Research and Awareness

Today, when researching biochar production and its applications, there are over 30,0000 peer-reviewed scientific research papers available to the public via the internet. Papers range from the various forms of pyrolysis and pyrolytic production methods to applications across agricultural uses of all scales and types, plus new, more novel applications such as in the building industry. Across this increased number of reports, there is a consensus and validation of the positive benefits of biochar.

Many of the scientific reports have been funded by governments and organisations who see biochar as a potential element in targeting Net Zero. New entrants into the industry should not lose sight of who is funding a particular report and what their motivations are behind it.

Figure 7. and Figure 8. Barley and Horticultural trials with different rates of custom-blend biochar. (Source: Author)

Companies with a motivation to use trials and reports as marketing tools for their products have the potential to not apply full scientific rigour. In Figure 7. a trial using differing rates of a custom-blend biochar was applied to a small barley trial. The number of plots were extremely small and not replicated, thereby not statistically large enough to accurately prove any results. This however did not stop the company promoting positive results of their product. The same was seen in a horticultural trial (Figure 8), where, in this case, the control plot had experienced restricted access to sunlight; however, this point was overlooked in their results.

The Internet, and in particular social media, has aided the growth of biochar as people and businesses have been able to use these mediums to widely share their knowledge and experiences. This information-sharing has aided a new generation of biochar enthusiasts who view biochar as a tool to help achieve their environmental and social goals.

Industry groups have played a vital role in the growth of the global biochar industry. Some of their key achievements include the creation and monitoring of production quality standards and controls, increased advocacy, and improved training services and collaboration. Some of the biochar industry groups are:

- International Biochar Initiative (IBI)
- Australian and New Zealand Biochar Industry Group (ANZBIG)
- US Biochar Initiative (USBI)
- US Biochar Coalition
- Biochar Europe

Growth of Regenerative Agriculture

Regenerative Agriculture (RA) is about reducing the environmental impact of farming and restoring the natural functions of soils, landscapes, and ecosystems, and continues to gain a growing global following. Practices like diverse crop rotations, cover cropping, minimal tillage, and the strategic use of animal grazing to improve soil fertility, sequesters carbon and reduces the need for synthetic chemicals.

Biochar can play many different roles in regenerative agriculture including:

- As a soil amendment that acts as a home for beneficial microbes and fungi, thereby fostering a diverse soil ecosystem with increased nutrient cycling, freeing up essential minerals for plant uptake, resulting in healthier plants
- Increases the water holding capacity of the soil, increasing drought resilience
- The porous nature of biochar and high cation exchange capacity can attract and store minerals that would have otherwise been leached away, keeping them available for plants later use
- To capture any potentially negative nutrient runoff into environmentally sensitive areas such as waterways
- To lock carbon in the soil for hundreds to thousands of years from waste biomasses that would have otherwise been released to the atmosphere

There has been a massive shift to regenerative farming globally driven by:

- Consumers are demanding products that are produced with improved environmental outcomes
- Many farmers looking for a sustainable way (both financially and environmentally) to farm now and into the future as they have experienced rising costs of chemical inputs with little positive results
- Government's increasing awareness of regenerative agriculture as a tool in the fight against climate change
- Regenerative agriculture proponents using their ability to influence crowds via novel social media or marketing channels

Climate Policies

Climate Change is a term that is in general use. The concentration of CO_2 and other greenhouse gases in the air are causing climate impacts such as heatwaves, dramatic floods, and rising sea levels. To combat climate change, CO_2 emissions need to be curbed rapidly, however this alone won't be enough. To keep the global temperature rise below 1.5ºC, which is regarded as a critical level, emissions will need to not only be reduced, but also remove and store some of the carbon that is already in the atmosphere.

Traditional ways to remove carbon dioxide from the atmosphere include planting trees and forestry, as plants remove carbon dioxide from the air naturally via photosynthesis, as do farms and soils that increase ground cover through cover crops and grazing management strategies. A challenge with these strategies is in the longer term; when trees and plants die, the carbon cycle returns stored carbon to the atmosphere as the plant material decomposes.

Newer, more novel strategies include:

- Biomass Carbon Removal and Storage (BiCRS) which includes a range of processes that use organic biomass to remove carbon dioxide from the air and then store it for long periods of time. Biochar falls within this category
- BECCS (Bioenergy Carbon Capture and Storage) involves generating energy using biomass and then capturing and sequestering the resulting CO_2 emissions. One example of this process is converting biomass to hydrogen, which can be used in a carbon-negative fuel
- Direct Air Capture (DAC) is the process of chemically scrubbing carbon from the ambient air and then sequestering it either underground or in long-lived products like concrete
- Enhanced Weathering, or Carbon Mineralization, is the artificial acceleration of the natural process by which certain minerals react with CO2, turning it from a gas into a solid that is permanently removed from the atmosphere

Among these novel strategies, BiCRS, and in particular biochar, has been identified as the most proven and economically feasible way to achieve carbon removal. The benefits of biochar CDR are further enhanced when waste organic biomass such as agricultural waste is used as the feedstock and the biochar is then returned to the farm as a soil amendment.

Governments around the world now understand that, to achieve their climate targets they will need to incorporate many of these strategies, thereby placing biochar at the forefront of their push towards "Net Zero". Certain governments are now providing financial incentives to farmers to start using biochar in their farming systems. Examples of such incentive programs are:

- USDA Natural Resource Conservation Service (NRCS), Soil Carbon Amendment, Code 336 (available through the US Federal Government)

  - After developing a Conservation Plan with a Technical Service Provider (TSP), and if biochar is identified as a tool, farmers can access funding through the USDA EQIP (Environmental Quality Incentives Program) for up to 75% (in some cases, up to 90%) of all eligible costs. This has dramatically dropped the costs of applying biochar to US farms, thereby increasing biochar adoption and demand

- California's Healthy Soils Program
  - This program has a similar approach to Code 336 but is limited to Californian farmers

- Denmark's "Green Tripartite Agreement", where part of the funds raised from livestock farmers, who will be taxed on their emissions, will go towards subsidies that reward farmers for sequestering carbon in soils using biochar
  - A subsidy is granted for the storage in Danish soil of biochar produced through the pyrolysis of organic materials
  - The aim is to incentivize farmers to use biochar as a carbon removal method, thereby helping Denmark meet its climate goals. It is not directly about increasing soil health, as Danish soils naturally have very high organic matter content; it's about using Danish soils as a storage unit for carbon
  - When this report was being written, the value of the subsidy was yet to be determined

- Australia is sadly lacking government support for the Biochar industry, an issue strongly supported by ANZBIG (the Australia and New Zealand Biochar Industry Group).

Ways in which Farmers benefit from using Biochar

Past misconceptions of biochar being a straight substitute for fertilizer has hurt the industry and slowed farmer uptake, but today farmers and businesses around the world are embracing and expanding their knowledge and applications for biochar. As information sources continue to grow, consumer and market expectations shift towards environmentally sustainable practices, and as biochar supply increases further, there will be greater opportunities for Australian farmers and businesses to start incorporating biochar into their operations. Key lessons from around the world of successful inclusion of biochar are:

- The mixture of biochar with compost
- Combining biochar with chemical fertiliser
- Biochar coated seeds
- Biochar in the livestock industry
- Uses for biochar outside agriculture

Each of these topics will be discussed below.

Biochar in Compost

Mixing Biochar with organic compost is one of the most common forms of biochar applications in agriculture. By including biochar into a compost blend and letting it brew for a while before applying to soil, the biochar can act as a sponge through its highly porous nature and cation exchange capacity which soaks up and stores beneficial microbes and nutrients in the compost. Biochar as a component of compost has been applied in urban farming systems in horticultural media as well as in broadacre pasture and cropping systems.

Flaxman Valley, South Australia

Ballintapper Farms are trialling using biochar mixed with pig manure in a custom-made compost blend they are producing on-farm. Biochar made from almond hulls was sourced, and before mixing into the compost brew, trace elements (zinc, sulphur, manganese, copper) that were determined to be lacking from their soils, were applied via a liquid spray to the biochar. The Biochar was then mixed with the pig manure and composted for around 12 weeks. Biochar accounted for approximately 20% of the compost's total volume.

Figure 9. Biochar and pig manure compost (Source: Author)

Prior to seeding the 20ha trial, the compost was spread with a muck-spreader at 10t/ha across their property. The compost was part of a soil health program they implemented which involved working the highly-compacted land with a Yeomans plough following the contours lines, spreading lime at 4t/ha to lift start lifting pH levels from 4.9 base average, spreading pig manure/biochar compost at 10t/ha and then sowing with a broad-leaf multi-species blend (field peas, vetch, tillage radish, forage rape, plantain, chicory and annual and sub clovers), as shown in Figures 8 and 9. Results have been very positive with soil tests indicating a large improvement in their micro biological activity as well as a balancing of the fungi to bacteria ratio. Their agronomist, Adam Krahnert says that "the results achieved in such a short time are amazing!"

Figure 10. Spreading the biochar and pig manure compost (Source: Author)

Biochar alone has not caused these positive results but has been a contributor to it. Key lessons from this trial have been:

- The trial needs to be replicated over numerous years to get better statistical results. It would have been interesting to see some further variations of rates, although some control areas were maintained
- The compost needs to have a consistent moisture level. It was a drought period through their composting period, which may have affected the compost quality
- When the biochar was blended with the pig manure, the odour from the manure was immediately reduced. This was a beneficial by-product as neighbours were close

- At true market values for both biochar and pig manure, compost mix would have been expensive but since they were able to source both products relatively cheaply the economics worked for them. Normally compost blends available in the market tend to only include around 2% biochar because of the prohibitive costs of biochar

California, USA

Monterey Pacific LLC is a large vineyard management company with more than 22,000 acres of premium winegrapes under contract in California’s Central and North Coasts and has been trialling and using biochar since 2015. In 2017 the company was part of a trial on the Oasis Vineyard where they took a compost, pure biochar and a compost/biochar blend and ripped it down 0.8 to 1 metre prior to planting a new vineyard (Figure 11). The aim of the trial is to put the nutrients and biochar at a depth where the plant’s root system can access it.

Figure 11. Deep ripping biochar/compost blend at Monterey Pacific LLC (Source: Sitos Group)

The trial has been ongoing with results published from their 6th harvest (Oasis Vineyard, 2024) identifying that every combination exceeded the results from the control. Even with the additional costs of the compost and biochar, the results proved that within less than two harvests each trial variant achieved breakeven and that the positive revenue continued to grow each year. By the sixth harvest the biochar/compost mix was averaging an extra 30% yield and had earned an extra US$14,947 of additional revenue (net of all costs) per acre with no negative impact on grape quality. Although this treatment was the most expensive in this trial, it also showed the greatest yield increase, which enabled the positive financial result.

Reasons cited for the positive results were increased water-use efficiencies from the trial treatments along with an increase in soil health measured by an increase in soil respiration, organic N and soil calcium. It is thought that an increase in beneficial mycorrhizae, which is known to shelter in biochar, may have extended the fungal hyphae to the vine roots, moving available phosphorus to the vine.

Key lessons from this trial are:

- Important to get the biochar/compost mix down to the root zone
- Although initial capital outlay is higher, the biochar/compost mix resulted in the best financial result
- Importantly, the yield increases from all trial treatments were greatest in the lowest yielding years, suggesting that the treatments increased the resilience of the crops

Monterey Pacific LLC are now using this method of deep ripping a biochar/compost blend into all new vine plantings. The Californian almond industry has been watching these results and a new partnership between Treehouse California Almonds LLC and Sitos Group with an investment of US$9 million in a new state-of-the-art biochar pyrolysis production facility was formed, which will take almond hulls and shells and turn it into biochar, to then be applied in the same manner prior to planting a new almond orchard.

Combining Biochar with Chemical Fertiliser

In an effort to help make biochar more accessible to broadacre farmers, the biochar industry has been researching and applying biochar in varying forms in combination with chemical fertilisers such as Urea and DAP using traditional farm equipment.

Coated Fertilisers

Biochar-coated fertiliser takes a conventional granular chemical fertiliser, like urea, and applies a Biochar coating over the surface. The aim of the coating is two-fold: to slow down the release of nutrients contained within the chemical fertiliser while also adding biochar to the soil to promote soil health and water retention.

Nutrient leaching and atmospheric loss are a huge cost associated with conventional fertilisers. The rate of loss is variable, depending on many conditions such as timing of application, weather around the application, and soil type. For example, when urea is applied to a paddock without rain, there can be a loss of 10% to 40% through ammonia volatilisation. The same rate of loss can occur in the soil when it is leached away by rain prior to uptake by the plants.

Coating conventional fertilisers with Biochar slows the release of nutrients, both into the atmosphere and into the soil, allowing plants to access these across a longer period. The biochar coating also has the potential to be charged (pre-loaded) with other desirable nutrients and microbes to suit specific plant and soil conditions. After the conventional fertiliser has fully dissolved the biochar will still be in the soil for over 100 years, acting as a haven for microbes, capturing, storing and making nutrients and water available to plants. If biochar-coated fertilisers continue to be used in the same soil over multiple seasons, the volume of biochar in the soil will slowly start to increase, along with soil organic matter, which will benefit soil health.

Figure 12. Biochar-coated urea (Source: Author)

Soft Agriculture in Mallanganee, New South Wales, is a stockfeed and fertiliser manufacturer who has developed their own biochar production facility to incorporate into their products. They are leaders in the Australian biochar industry and supply biochar-infused stockfeed and compost, as well as biochar-coated fertilisers. The demand for their biochar-coated fertilisers has been limited as the relatively high cost of the product is a deterrent to end users.

Challenges with biochar-coated fertilisers have been:

- High unit costs. An example is urea coated with biochar. Straight urea may lose around 30% to 40% of its nutrients through leaching or ammonia volatilisation when applied to the soil. The current cost of applying a biochar coating to urea is higher than the savings from reduced leaching. When urea prices skyrocket and availability is more restricted, biochar coating becomes more economically viable. This simple cost analysis does not consider any gains to soil health.
- Depending on what binding agent is used, certain polymers take a long time to breakdown in the soil
- Again, depending on the binding agent used, the Biochar coating can "sweat" and lose contact with the urea making it difficult to handle and store.

Mixing Biochar with Fertilisers

A potentially lower cost method of application to reduce the leaching issue of conventional fertilisers in to simply mix biochar with the fertiliser at or ideally before seeding and sow them together. This technique may not have the efficiency of biochar-coated fertiliser but is a simple way to utilise biochar to reduce leaching losses.

Farmers have endured challenges calibrating and sowing when biochar of uneven size is used. Machinery also tends to get blocked when moisture gets in. Granulated and pelletised biochar is now becoming more available, providing farmers with a product of consistent size and weight to overcome earlier problems. Biochar is initially ground to a fine powder, any specific nutrients and microbes are added, then a binder such as silicon is added when it enters the granulising machine. This results in an even sized granule that is easier to handle and use.

Figure 13. Granulated biochar produced at Soft Agriculture (Source: Author)

Liquid fertilisers incorporating biochar are only in limited supply, although theoretically sound, but expensive. Sitos Group in California are developing a liquid biochar fertiliser that takes micro-sized biochar particles that are pre-loaded with specific microbes and nutrients and suspends them in liquid. This fertiliser can be delivered by existing fertigation systems and is gaining interest in the Californian almond industry.

Biochar Coated Seeds

Seed coatings are becoming more popular. Coating seeds with biochar can improve germination, seedling vigour, and crop yields by protecting seeds, holding moisture, and delivering nutrients.

Seed bombing is a novel approach to reforestation where a seed is coated in biochar and then thrown from a plane. The biochar coating protects the seed from predators like birds and insects, shields it from extreme temperatures, and retains moisture to create a beneficial micro-environment for germination once the rains arrive. This technique allows for the rapid and cost-effective seeding of large or hard-to-reach areas to reforest degraded landscapes.

Biochar in the Livestock Industry

Biochar is being used in animal feeds with the aim of improving livestock health through promoting favourable gut microflora, binding of mycotoxins and removing pathogenic organism such as Campylobacter. Through this process it improves the health off the rumen, the area for energy exchange, which leads to increased liveweight gain, and boosts the health of the rumen, which reduces the incidences of sickness.

Methane emissions from cattle can also be reduced through using biochar feed additives, although results depend on the type and quality of biochar used and feeding systems applied. Biochar that is designed Fit-For-Purpose (FFP) (specific pyrolysis feedstock, temperature control and nutrients supplied) can effectively target the methane-producing microbes in the rumen or adsorb the methane gas itself. This is achieved by the biochar altering the microbial communities in the rumen, favouring those that lead to less methane production or more efficient digestion. It is not a silver bullet to eliminate methane emissions but, when used correctly, can reduce methane emissions.

A 2020 research project conducted by Climate and Agricultural Support's Melissa Rebbeck fed biochar to dairy cattle in South Australia (Tahery, et al. 2022). A herd of 250 Jersey cows were fed 150 grams per day of biochar that was mixed into their complete ration, across a year the trial showed an average milk yield increase of 1.4 litre/head/day. With biochar costing AU$11,000 for the year and the increase in revenue from the higher milk production totalling AU$70,000 for the year, net profit from using biochar in dairy was close to AU$60,000 for the year. The trial also indicated an increase in feed conversion. This meant a further annual saving of AU$12,000 in fodder.

A co-benefit of this trial was seen in the pastures where the dairy cattle grazed. The cattle had spread their biochar-laden manure across the paddock and dung beetles then buried the manure deep in the soil. The result was a noticeable increase in soil health and soil pH as the biochar was enriched with nitrogen-rich organic compounds during the cattle's digestion process, which turned the excreted biochar-manure into a more valuable organic fertiliser. This result confirms many other scientific and anecdotal reports that have identified improvement in pastures where livestock who have eaten biochar have grazed.

Biochar has also been directly applied to livestock bedding in chook farms and piggeries. The adsorptive qualities of biochar are being used to capture moisture, ammonia and nitrate. According to a 2012 research publication from Gerlach and Schmidt (2012), the nitrogen adsorption and the continuous drying of the litter deprive the microbial pathogens of their nutrient base and reduce toxic emissions of ammonia. Biochar also benefits broiler chickens, who frequently suffer from leg weakness syndrome and footpad dermatitis, the main causes being high levels of ammonia (NH_3) and overly damp litter. Biochar not only reduces the ammonia odour (capturing ammonia) but also improves the chicken's health. As with cattle, an additional benefit is improved soil health when the nitrogen-rich bedding is removed and applied to pastures.

Biochar as a manure management tool has large potential. The ability to capture ammonia odour provides a unique marketing tool for manure sales. On pig manure with biochar compost trial at Ballintapper Farms it was noted that when the biochar was applied to the pig manure piles, the odour was dramatically reduced, a very positive outcome given the relative proximity to neighbours.

On a regulatory front, in the USA there is only limited use of biochar as a feed additive as the FDA have tight regulations regarding feed additives. In Europe, Asia and Australia there are not the same level of restrictions.

Uses of Biochar Outside of Agriculture

As the biochar industry continues to grow and attracts a new entrepreneurial drive, so does the range of applications outside of the traditional agricultural context. Some of the biochar applications include:

Urban Green Spaces

Councils and private industry around the world are using biochar when establishing new urban parklands. The Stockholm Biochar Project used municipal green waste as a source material, turned it into biochar, used the excess heat energy in the city's heat supply and then used the biochar for urban green spaces development. The project also gained global attention for the application of biochar in new mature tree plantings to improve their initial growth and survival rate. This has become known as the "Stockholm Trench".

In Australia, councils around Melbourne are sourcing Biochar from the Yarra Ranges Biochar facility operated by Earth Systems to incorporate into new urban green space plantings. Councils are now recognising biochar's role in soil health and seeing the economic benefits of increasing the survival rates of mature tree plantings. The facility has forward sales 18 months in advance, such is the high demand.

Built Environment

There is a growing interest in biochar's application to building materials such as concrete, asphalt, insulation and steel making. Still classified as a niche sector, it does offer a further potential use for biochar.

Biochar incorporated into a concrete mix (at a rate around 2%-5%) has the potential to improve the compressive strength of cement by 30% (RMIT) whilst also enabling the concrete and sand components to be marginally reduced. Real world trials have been conducted in Melbourne with RMIT working with Major Road Projects Victoria (MRPV) to build new footpaths made from biochar-infused concrete. A major attraction of incorporating biochar is for the "green" credentials of biochar, reducing the carbon footprint of concrete.

The same principles of biochar application also apply to the asphalt industry with biochar being included in many new road mixes. Biochar used in concrete and asphalt needs to be made fit-for-purpose, as incorrect utilisation can reduce the strength and life of the concrete and asphalt.

Biochar of high quality (high carbon content, low ash) is being used in the metallurgical process of steel production as a partial substitute for traditional fossil fuels such as coal and coke. EnviraPAC Monticello LLC in Arkansas USA have found a profitable niche market for their 91% carbon, 1-2% ash biochar (they use the term "renewable carbon products"). Their customers are US steel manufacturers who are looking for a renewable substitute for Petcoke, as there are issues with supply coming out of Siberia arising from an anti-Russian sentiment.

Applications of biochar in insulation, bricks and packaging are continuing to be made but at a very niche level and will struggle to shift significant biochar supply away from the traditional uses on agriculture.

Water Filtration and Land Remediation

Biochar is gaining attention in both water filtration and land remediation. Biochar’s porous nature, ion exchange capacity and size can attract and capture contaminants such as organic compounds and pesticides, inorganic substances like heavy metals and larger particles like bacteria, making it an attractive resource for companies trying to remove impurities from water and soil.

Business Models for Australian Farmers to Establish Biochar Production Plants

There are a wide range and scale of businesses currently manufacturing Biochar around the world. Potential models that could apply to Australian farmers are:

Medium-Scale Centralised Model

Fixed (centralised) pyrolysis units with an annual feedstock intake of between 3,000 – 9,000t/year and producing around 1,000 – 3,000t of biochar are gaining popularity, as the size is large enough to gain some economies of scale and can access multiple revenue streams whilst being small enough to keep the capital outlay achievable. Prices vary hugely depending on the level of automation, add-on equipment and infrastructure required and the quality of biochar and energy produced. Prices between AU$800,000 and AU$4,000,000 are common. Pyrolysis units of this size tend to be scalable to fit within future growth strategies. Sitos Group in California are starting their new commercial facility with 1 pyrolysis unit and will quickly add 2 more which all will be able to utilise the same infrastructure (chippers, driers, packaging etc).

Most of the active biochar producers in this market category tend to be indirectly involved in agriculture. They are either a separate biochar manufacturer with strategic partnerships with agricultural end users (eg Sitos Group in California who have partnered with Treehouse California Almonds) or compost/landscaping suppliers who are value-adding their biochar through their compost sales (Sonnenerade in Austria).

There are many good examples of horticultural businesses who are today using the energy created by pyrolysis units to heat their glasshouses. Holla-Fresh in Tantanoola in South Australia is Australia's largest producer of hydroponically grown herbs. To reduce their reliance on fossil fuels to heat their glasshouses, Holla Fresh installed a pyrolysis unit in 2020 focussed on energy creation. They formed a strategic partnership with a local landscape business who supplies them with wood chips as a feedstock, and after they have been pyrolysed, the landscape company collects the biochar to be incorporated into their commercial compost sales. This is a great example of strategic partnerships creating a circular economy.

The theory of this model can also apply to the broadacre farming sector, although trying to conduct an analysis is difficult, as the few that are doing it are reluctant to share actual data. A theoretical example would be a grain grower who sets up a biochar plant on farm, uses their own cereal straw as a feedstock and then uses the biochar on their own paddocks. If this grower could also utilise some of the heat energy, a strong business model could exist.

Issues to consider for medium-scale centralised model

Common themes and issues experienced by biochar producers around the world who are already in the market include:

Need to maximise revenue streams

- The most profitable and resilient biochar businesses are the ones that are generating income from at least 2 of the 3 main revenue sources. Biochar and energy generation or biochar and carbon credits are the most common forms at this scale. The consensus view is that the global price of physical biochar will fall in the future as total supply increases, driven by the large quantity of biochar that will hit the market as more CDR projects become operational. Establishing a business based on only raw biochar sales is risky if cannot achieve low production costs

Consistent feedstock supply and quality

- Securing a consistent supply of feedstock to run the pyrolysis unit for 12 months of the year is a vital first step. If the desire is to produce a consistent quality of biochar, then a consistent feedstock is essential. Swapping between feedstocks such as wood chips and cereal straw will not only cause challenges for the pyrolysis unit in many cases, but it will also produce significantly different types of biochar, which will impact the marketing strategy

- Using a consistent size, density and moisture content of feedstock is essential for speed and ease of operations. At the Yarra Ranges Council in Victoria where Earth Systems operate a pyrolysis unit, initial feedstock from municipal green waste was sourced from the council. However, due to the inconsistent size (even after chipping) and density from having a mixture of sticks, leaves and grass clippings, it was deemed easier and more profitable to use only the wood chippings from urban tree-clearing companies instead

- If selling carbon credits is part of the revenue plan, ideally the feedstock will be sourced from within close proximity as all freight costs account towards the Lifecycle Assessment of the carbon credits. The feedstock also needs to be deemed a waste product to claim carbon credits, as biochar cannot earn carbon credits if a crop such as bamboo is grown for the sole purpose of a providing a feedstock for biochar

- Successful businesses are using low-cost to free feedstocks, or in some cases are being paid to take the feedstock. This can have a significant impact for the viability of the whole project

Selection of Pyrolysis units

- Choose a pyrolysis unit that will best match your production goals and available resources. Certain brands and types are geared more towards a certain attribute (ie geared to energy generation or infusing minerals) or can only handle a certain type of feedstock. Using the correct machine from the start will result in the highest efficiency

- Operating at extreme temperatures, often for extended periods of time, and other times more of a start-stop nature, will naturally put stress on the construction materials. Large losses of heat energy and inefficiencies have been observed from the use of low-quality steel and/or poor design. Saving money at the start can lead to higher expenses to rectify the problem down the track

- To efficiently operate a pyrolysis unit, feedstock is needed to enter at a consistent speed, size, shape and moisture level. This will generally require pre-processing of the feedstock. Dryers and chippers can utilise some of the energy produced from the pyrolysis unit, thereby reducing overall energy costs

- As the industry for pyrolysis unit production has grown, so has the competition to sell them. This has led to many exaggerated claims about the capabilities of a particular unit. Assumptions based on operating 24 hours per day, 7 days a week, all-year round are unrealistic but seem to be a common occurrence. These claims are made on theoretical assumptions, not proven data, as most of the technology has only recently moved from the R&D stage into commercial operation. Businesses currently using these units have not experienced anywhere near the promoted level of production

Maximising end-product sales

- If intending to sell biochar, establishing the target markets early will guide the overall production process. The consensus view in the industry is sales of raw biochar alone is the least profitable option. Value-adding biochar through methods such as infusing with minerals/trace elements, adding to composts or creating biochar-coated fertilisers will significantly increase margins

- The end-user market for biochar is still in its infancy and requires a lot of education. This can be expensive and time-consuming for individual businesses. Creating strategic off-take agreements can secure markets and reduce the complexities of individual sales

- Carbon credit sales sound great in theory, but the reality in Australia there have been very few completed. To be able to create, and then sell carbon credits into the international voluntary carbon market (biochar is not yet classified with Australia's ACCU scheme), production units need to be accredited with a standard such as Puro.earth and a full Lifecyle Assessment must be done. The complexities and costs of meeting these standards have restricted the number of producers in the medium-scale category from earning a revenue from carbon credits. The ones who do are operators of large-scale CDR projects where carbon credits are their main revenue source

Small-Scale (Artisan) Mobile Model

This category includes at a base level for biochar production equipment such as Kon-Tiki kilns and flame-cap kilns. The next step up in technology (and price) in this category are air-curtain burners and trailer-mounted pyrolysis units.

Kon-Tiki and flame-cap kilns have a central open-top cone or drum where the feedstock is burned with an outer ring providing safety to operators. The design of the cone/drum creates a unique "flame curtain" burn ensuring that there is minimum oxygen at the bottom where the biochar is created.

Figure 14. Kon-Tiki Kiln (Source:.The Biochar Revolution)

There are some key benefits to operating at a small-scale mobile level of biochar production including:

- Equipment, especially at the base level, is cheap, accessible and can be easily manufactured around the world
- Suitable for small operations wanting to use biochar with minimal investment
- The portability of small-scale equipment allows the producer to go to the feedstock, helping to access remote areas. It is also useful for feedstocks that are in small amounts and spread widely
- The low cost of entry enables more future participants to manufacture and use biochar, building supply and demand in the whole industry
- Can generate carbon credits if all accreditations are obtained

Challenges of this model include:

- Very small scale, labour intensive and time consuming to produce any significant volumes of biochar
- Quality of biochar produced is extremely variable, as it is difficult to put effective temperature controls in place
- Lower carbon content in the biochar as more CO_2 escapes into the atmosphere
- Although carbon credits can be generated, there are some significant complexities and the conversion rate to carbon credits is lower

Medium-Scale Cooperative Model

Set in the heart of the Chianti Classico region of Italy, Frantoio Del Grevepesa is an olive processing and marketing cooperative with over 180 member-farms of all sizes. Its purpose is to promote and protect the environment, and the flavours and traditions linked to the production of extra virgin olive oil. Today it produces over 300,000 litres of extra virgin olive oil.

To reduce the Co-op's energy bill, the Co-op explored different solutions and is today working with the team at Yanmar R&D Europe (Florence) to implement Yanmar's Farm Circular Solution (FCS) into their business (Diagram 3.)

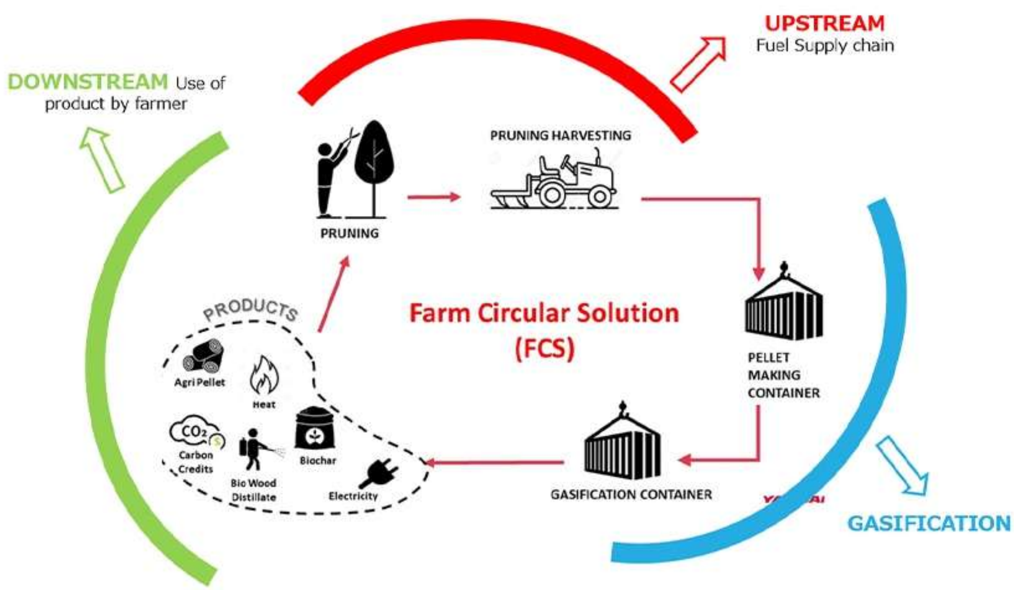

Diagram 3. Yamar's FCS at Frantoio Del Grevepesa, Italy (Source: Yanmar)

In the Chianti Classico region, many olive producers also have grape vines on their properties. Member-farmers collect and deliver their vine pruning to the Co-op. The pruning are then dried and pelletised to be a uniform shape and density before entering their gasification system. Gasification and pyrolysis systems are very similar, however the key difference being that, in a gasification system, there is a controlled use of additional oxygen which produces a larger quantity of syngas at the cost of a reduced amount of biochar. As power generation was the focus of the Co-op, this gasification system was chosen.

Figure 15. Small bales of vine pruning at Frantoio Del Grevepesa Italy (Source: Author)

The vine pruning pellets enter the gasification system to produce syngas which is converted to electricity with biochar considered a by-product. The Co-op is now producing excess electricity with additional supply sold back to the national grid. The biochar is returned to the member-farmers who are then applying it to their soils completing a circular economy.

Key take home messages from this model:

- Frantoio Del Grevepesa identified their need, and selected a system that would suit their power creation demands and availability of feedstock

- This circular economy could be applied to existing Co-ops in Australia that can leverage their member base for feedstocks whilst reducing net operating costs of the business

- Can also be applied to new Co-ops dedicated to biochar production. A possible example is a group of broadacre farmers who form a co-op to build and run a biochar production facility which is co-located with an energy-user such as a greenhouse, winery, or other industrial manufacturer. Members supply cereal straw as a feedstock and purchase back biochar from the facility to be applied to their soils. Income from the facility would be biochar sales to member farmers first, then from biochar sales if there is sufficient supply, revenue from energy sales to the co-located partner and potentially from the issue and sale of carbon credits
    - The advantage of this model is that for individual farmers the initial capital outlay is vastly reduced, and the risk arising from operation of the facility is shared amongst the co-op members

Conclusions

The biochar industry is full of passionate people inspired with the belief that biochar is a tool that will help save the planet. Many have been working for years to promote the benefits of biochar, not just as a durable method to capture and store carbon, but as a valuable addition to many industries.

Global trends have shifted towards converting traditional industries to sustainable, "green" operations to reduce their environmental impact. Consumer expectations, the rise of regenerative agriculture and encouragement from Governments around the world is seeing a move away from the reliance on chemical-based inputs. At a political level, parts of Europe are embracing biochar as a key component of their push towards Net Zero targets. The global momentum is rising and will make its way to Australia in time, allowing Australian farmers today the opportunity to watch and learn from or Northern colleagues.

Technological improvements in pyrolysis production equipment have vastly increased the scale of commercial quantities of biochar entering the market which have reduced the supply issues experienced in the past. Demand will keep following its growth path, as markets continue to develop for different uses of biochar in agriculture, industry and environmental purposes. This will be financially supported by the production and sale of the byproducts of pyrolysis-production (energy and carbon credits).

As more manufacturers of pyrolysis technology enter the market, the price of equipment is likely to fall, creating opportunities for farmers to produce their own biochar at a commercial level. Successful biochar entrepreneurs will be the ones who are able extract maximum value from the sale of physical biochar, energy production and carbon credits.

Recommendations

Farmers:

1) Education targeting the benefits and the challenges of using biochar in individual businesses in an essential first step. The information is available with over 30,000 peer-reviewed published research articles relating to biochar. ANZBIG is a great resource. Through conducting trials on farm, first-hand experience can be gained

2) Points to consider when investigating building and operating individual biochar production plant are:
    a) Proper feedstock selection (location, availability, cost structure) is vital
    b) Select the pyrolysis equipment that will meet needs (matched to the location and type of feedstocks, drying requirements, mineral-infusing biochar, energy-production focus, etc)
    c) Investigate business models that create and leverage strategic partnerships
    d) Look for ways to optimise at least two, if not all income streams from pyrolysis production
        i. Biochar - value-adding raw biochar and creative marketing strategy
        ii. Carbon credits - building own "brand" to access voluntary carbon market
        iii. Syngas - Own use of energy and/or offtake agreements

Industry:

1) Continue and expand on the work of ANZBIG and private industry in building awareness of biochar applications in agriculture and beyond
    a) Direct education of commercial agronomists and nutritionists, not just regenerative or organic focused ones. Agronomists and nutritionists are a trusted source of advice and information for farmers

2) Lobby Australian Government for methods to incentivise the production and adoption of biochar. There could be incentives to reduce capital costs of establishing pyrolysis production unit or subsides for end-users for application of biochar

3) Continue to work towards biochar's inclusion into the Australian Carbon Credit Unit Scheme

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