Supplementary Submission No 234a

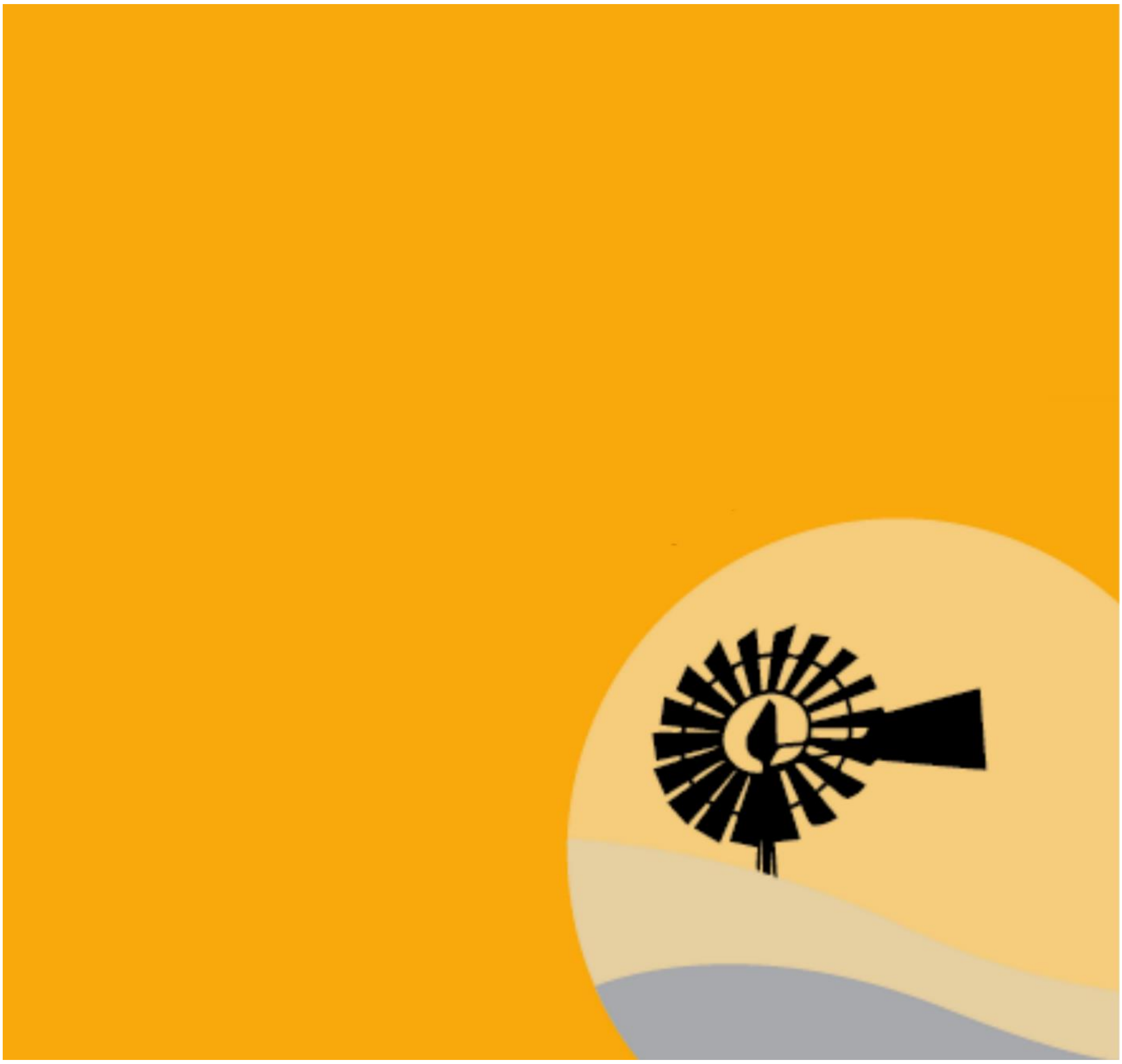
INQUIRY INTO LONG TERM SUSTAINABILITY AND FUTURE OF THE TIMBER AND FOREST PRODUCTS INDUSTRY

Organisation: Western Murray Land Improvement Group

Date Received: 29 April 2022

Wood Waste and Crop Residue Opportunities to Increase Agricultural Productivity and Reduce Environmental Impacts

April 2022



Contents

Considerations for the NSW Timber Industry Enquiry

This submission is specifically aligned with the Terms of Reference of the NSW Parliamentary Inquiry into the long-term sustainability and future of the timber and forest products industry relating to the following (in bold text):

(b) the impact of external influences on the timber and forest products industry, including but not limited to **drought, water, fire, regulatory structures, habitat protection and local, State and Federal policies regarding climate change** and plantation establishment,

(e) **opportunities for the timber and forest products industry, including but not limited to drought, water, fire, regulatory structures, habitat protection and local, state and federal policies regarding climate change** and plantation establishment.

(f) the role of the government in addressing key economic, environmental and social challenges to the industry, including funding and support to encourage improvements in forestry practices, training, **innovation** and automation, workplace health and safety, industry and employee support, **land use management and forestry projects**,

(i) best practices in other Australian and international jurisdictions in relation to the sustainability of the timber and forest products industry, including **social sustainability, community and Indigenous engagement and multiple uses of the forest estate**.

(j) **other related matters**

Executive Summary:

Biochar is a form of solid residual black carbon derived from the thermo-chemical decomposition of renewable biomass feedstock such as wood, crop residues, manures or leaves, heated in a closed container at relatively lower temperature (<700 degrees C) under oxygen limited condition and specifically prepared for soil amelioration and Carbon (C) sequestration.

This submission explores the use of using wood waste with crop residue as feedstock for biochar production and associated by-products, which has the potential to realise considerable direct and indirect socio-economic and environmental benefits.

Potential direct economic benefits of $43 to $102M per year have been calculated, pending a range of factors such as biochar prices and Australian and International carbon credit unit prices, with an estimated 35 multidisciplinary jobs created. These jobs range from equipment operation, marketing, communication, logistics, transport and research and development roles including First Nations people working on country.

Infrastructure and technology associated with the pyrolysis process have the potential to produce flow on benefits of $99M to $235M using a regional economic activity multiplier of 2.3 (SEGRA 2019).

There is potential to reduce greenhouse gas emissions by 123,000 tns per year via carbon sequestration, emissions reduction (e.g. livestock feed additives) and emissions avoidance measures (in the case of finding alternatives to crop residue field burning).

Indirect, unmeasured benefits of biochar include improved soil moisture holding capacity and nutrient cycling, plant production and animal health. improved air quality, reduced chemicals inputs and reliance on imported products to Australian Agriculture.

This project would be further scoped with an existing biochar cluster group that is envisaged to be expanded to involve a range of local and state government, business, community and research institutions.

Introduction:

In general, extensive literature is available on biochar formation, characterisation and its potential applications as a soil ameliorant, adsorbent, impact on soil biota, impact on bioremediation of contaminated soil and GHG emission reduction focusing on wood as a feedstock material. Biochar can be added to soil as a soil conditioner, and as a livestock feed additive improving feed conversion efficiency, production and reducing methane emissions. The nutrient retention capacity of biochar leads to reduction in fertiliser use, so it indirectly results in reduced environmental costs associated with the production of chemical fertilisers and energy for supply and distribution and land application.

Other novel applications of by-products associated with the biochar pyrolysis process have agricultural and industrial applications. These include bio-stimulants, bio-insecticides and bio-fungicides from pyroligneous acid generated in the process. Tar / bio-oil and tannins (used in conjunction with biochar for feed additive methane reduction), bioenergy (from syngas), and carbon / graphene (used for applications such as activated carbon for water filtration and battery manufacture), bioenergy and industrial grade CO2 are other examples of its use.

Several hundred tonnes of wood waste derived from the Red Gum Timber Industry is currently utilised for compost on a local dairy and avocado farm which forms an important agricultural input, reducing the reliance on chemical fertilisers and showcasing an opportunity for novel biological product inputs. A local case study of this process is outlined in Appendix A.

This opportunity, which already has working examples in other locations, provides a clear linkage between the stated community consultation outcomes in the main submission to retain a working forest that benefits the whole community, including the agricultural sector, in order to provide positive economic, social, cultural and environmental outcomes.

This scoping document investigates the opportunity to scale up the use of both wood waste and crop residue as a local feedstock for biochar and other derived products for environmental and economic benefits. Both feedstocks are readily available and are in close proximity to each other in the region, and according to scientific literature review, there are beneficial synergies for using the two feedstocks for biochar production as processing crop residue in isolation without wood waste would likely be unviable; and unattractive from a chemical composition perspective for alternative uses, particularly agriculture.

A local biochar cluster group has been formed in the region supported by Western Murray Land Improvement Group (WMLIG) via funding from the Federal Government's Murray Darling Basin Economic Development Program.

The cluster group is keen to pursue opportunities for the use of biochar in local agro-ecosystems and has started with crop residue biochar trials and analysis. Other opportunities are being scoped that reinforce the valuable cooperative project work currently underway in this region; work that can't be separated from the future of the KP Forest.

Australia has a high potential for low-cost carbon drawdown provided by pyrolysis and gasification technologies. Increasing uptake of biochar and bio-sequestration bioenergy technologies aligns to the Federal Government's 2030 National Bioenergy Roadmap.

These include carbon removal through Pyrogenic Carbon Capture and Storage (PyCCS) and Bioenergy with Carbon Capture Utilisation and Storage (BECCS/BECCU). It is recognised that there is a need to apply this to larger scale demonstrations and provide broader awareness of benefits to help accelerate the industry and provide regional beneficial outcomes (Australian Renewable Energy Agency, 2021).

The biochar industry sector has the potential to contribute significantly to the following:
Socio-economic:

- **Rural and Regional employment**, including substantial multiplier effects in upstream (biomass supply etc) and downstream (markets) industries
- **Mitigation of the 'brain drain' and 'youth drain' from the bush** toward larger cities, through provision of employment in exciting new green technologies and applications, including many still with direct contact (and benefit for) the land.
- Opportunities for **Indigenous employment** as part of fire stick management and land rehabilitation, especially removal of woody weeds and excess course woody debris.
- **Assist PostCovid 19 Recovery** – new jobs and green jobs, potential high growth sectors
- **Assisting food and energy security**
- **"Turbo-boosts" to other sectors** (e.g. agriculture productivity, drought resilience)
- **Circular economy** (wastes to resources of higher value) – today many recoverable organic residues are burned or landfilled, such as plantation wood residues and crop stubble etc.
- **New Carbon Economy** (Carbontech, biobased materials) – US domestic market potential alone estimated at >$200B per annum for solid carbon products (Carbon 180, 2019).
- **Complementary to other forms of bioenergy** (e.g. can improve gas quality and quantity in Anaerobic Digestion for biogas etc).
- **Complementary to other forms of renewables** (e.g. potential for graphite from biochar for Li Ion battery production, bioenergy for dispatchable energy and potential for cogeneration with solar/wind (allowing 24/7 operations, reducing terms for ROI on those technologies).
- **Opportunity to accelerate through further support:** The Australian Renewable Energy Agency (ARENA) has spent over AUD $118M on the bioenergy sector in the last 8 years. Supported projects involving biochar are limited to date (e.g. Logan Biosolids Gasification Project) and as such the sector represents significant potential for further consideration and investment.
- **Cost savings for local government and regional state government services –** Such as a collaboration by the Pyrenees Shire Council in Victoria and the Beaufort and Skipton Health Service network to power the local hospital and aged care facility using straw pellets and local sawmill wood waste.
- **Circular economy** and waste minimisation
- **Land remediation and rehabilitation**

Environmental:

- **Critical action on climate change** – significant carbon dioxide removal (drawdown / sequestration), along with continued emissions reduction in destructive gasses such as nitrous oxide and methane.
- ***Drought resilience*** for farms and also urban vegetated areas (reduced water requirements for soils and sporting fields etc). Biochar absorbs up to several times its weight in water.

The potential benefits of using wood waste with crop residue as a feedstock in a pyrolysis process (as recommended by Singh et al, 2015), has been calculated by WMLIG using a blend ratio of approx. 2:1 crop residue to wood waste (30,00tn crop residue with 17,000 tn wood waste). The annual potential direct and indirect benefits of this use case are compelling and summarised below:

Calculated potential direct benefits to the local region

Socio-economic

- **35 local jobs, comprised of:**
  - 5 Traditional Owner jobs working 'On Country' in the Koondrook Perricoota Forest.

- 22 people working on processing material to a final value add product ready for sale,
  - 3 transport jobs,
  - 3 market and communications jobs,
  - 2 R&D agricultural trial work jobs.
- **Direct economic benefit of between $43M to $102M per year**. This wide range is dependent upon pyrolysis conversion efficiency and price achieved for carbon offsets and finished products. The potential economic benefits are comprised of:
  - Biochar value $8.4M to $51M/yr (see Appendix C)
  - Wood vinegar value $4M to $6M/yr (see Appendix C)
  - Biochar CO2 offset $1.5M to $6.1M/yr (see Appendix C)
  - Livestock feed additive methane offset $1.85M to $7.8M/yr (see Appendix C)
  - Crop residue CO2 equivalent in field burning avoidance offset value for local farmers $1M to $4.35M.
  - Value add wood waste (Est. $0.8M/yr)
  - Labour $7.3M/yr
  - Feed additive livestock production benefit of $18.67M *(if 20% of biochar was used as a feed supplement @$280/cow/yr x 66,666 cows using rate of 150g/biochar/day). See Appendix B example.*
- Infrastructure and technology required for organic waste conversion to bioenergy, biochar, and related finished products est. $20M+ *(not included in economic benefit calculation).*
- **Indirect economic benefit of $99M to $235M per year** using economic activity multiplier effect of 2.3 (SEGRA 2019).

<u>Environmental</u>

- **Reduce Greenhouse Gas (GHG) emissions by 123,293 tns CO2 equivalent. This is comprised of:**
  - 41,310 tns/CO2 reduction converting wood residues to biochar,
  - 52,983 tns/CO2 equivalent reduction using biochar as a feed additive to reduce methane livestock emissions.
  - 29,000 tns CO2 equivalent reduction from not burning rice stubble in field (avoidance).

Unmeasured indirect potential benefits

There are a range of indirect benefits associated with the production of biochar that have not been economically valued in the benefits analysis. For example, using biochar as a livestock feed additive to improve feed conversion efficiency, reduced fertiliser use and improved animal health (including reduced vet costs). A list of the potential multi-use benefits are outlined below:

- **Improved air quality and amenity** from reduced PM2.5 and PM10 particulates generated from crop residue burning (rice in particular).
- **Improved animal health and production** when biochar and other products such as bio-oil and tannins are included as a feed additive.
- **Improve soil and plant health:**
  - Improved soil organic matter and associated cation exchange and soil moisture holding capacity.
  - Soil ameliorant and carbon sequestration. Improves soil basic properties such as pH (ameliorates soil acidity) along with subdued release of greenhouse gases from agroecosystems.
  - Adsorbtion surface to agrochemicals and therefore can bioremediate contaminated soil improving environmental health and food safety due to reduced uptake by crops and chemical leaching.
  - Provision of important micro and macro nutrients and long-term nutrient retention capacity.

    - Biochar aggregates hold nutrients and soil moisture providing suitable habitat for microbial communities and better symbiosis of crop with bacteria and fungi leading to bioavailablity of nutrients.
    - Suppressed agricultural plant diseases, and increased plant growth. (El-Hadal et. al. 2010, Youssef 2014).
- Create an **agri-innovation demonstration site** / innovation ecosystem transferrable to other regions and leverage regional produce branding opportunities:
    - Establishment of place-based research partnerships and cross-industry networks that collaborate for technological and innovative solutions and create an institutional innovation mindset. This aligns to the One Basin CRC and drought resilience and innovation hub programs.
    - WMLIG has submitted a Quickstart program as part of the One Basin CRC investigating a collaborative project for conversion of waste organic matter to produce novel biological products to increase agricultural production and reduce environmental impacts. This helps build resilience by adaptive measures (which aligns to Murray River Councils Adverse Event Plan), educate community and instil an ''Institutional Innovation'' mindset.
    - Position region as leader in sustainability and innovation.
    - Involvement of businesses in the new carbon economy.
- **Produce niche high value products:**
    - Feed additives,
    - Prescriptive soil ameliorant and decontaminant (different feedstock mixes and pyrolysis temperature can influence soil pH - increased soil cation exchange capacity also provides liming effect to acidic soils which immobilizes heavy metals and persistent organic pollutants),
    - Bio-insecticides, bio-fungicides, and bio-stimulants,
- **Food and energy security:**
    - Reduced supply chain sovereign risk by reducing reliance on imported products.
    - Opportunity for bioenergy production and alignment to the National Bioenergy Roadmap.
- **Reduce financial costs for food and fibre producers**; demonstrate potential for new business opportunities, while addressing climate change/resilience-building initiatives and reducing waste:
    - Increase $/ML water returns (improve soil moisture holding capacity, reduce inputs, income from carbon economy, value add agricultural wastes).
    - Provide additional income to primary producers.
    - Create new industries (diversification), jobs (including Indigenous employment).
    - Reduce waste streams.
    - Direct farm to market value-add opportunities. Positive farmer backstory leverage for produce access to niche high value markets to discerning buyers.

Local resource availability and opportunities for First Nations people

The volume of local red gum wood waste residue generated is greater than 17,000 tonnes per year which has a potential to be converted to 8,500 tonnes per year of biochar, and other useful agricultural products such as wood vinegar (pyroligneous acid).

Traditional Owners have a strong cultural intention (John Kerr, CEO Moama LALC pers. comm. 2021) for reducing coarse woody debris fuel loads in the forest, as they are at a level not seen for thousands of years, putting important cultural heritage sites at risk from out of control bushfires (e.g. birthing and other culturally significant modified trees). Local fire services have noted that there are areas with unacceptable levels of coarse woody debris which would result in crown fires, which have historically been a very rare occurrence in the red gum forest estate to date, and would welcome a reduction in fuel loads.

Log jams change flood water dynamics through flood runners in the forest by increasing deposition in waterholes. This reduces the amount of time water is present to provide wildlife refugia support and subsequent re-seeding of native fauna and flora to repopulate the forest in subsequent flooding events.

In this proposal an estimate of 2,000 tonnes per year of wood residue is proposed to be harvested by Traditional Owners, employing five full time people. (*Note that this proposal would require EPA regulatory support in the case of flood runners, as well as further dialogue with Forestry Corporation and other forest users. However, in saying that, the proposal aligns with the NSW Parliamentary Inquiry into the long-term sustainability of the timber and forest products industry, especially in relation to:*

- *Industry engagement and multiple uses of the forest estate.*
- *Drought, water, fire, regulatory structures, habitat protection and State and federal policies regarding climate change.*

The Value of Crop Residues

In addition to wood residue, the local region has significant quantities of agricultural crop residues that can be converted to biochar, particularly wheat, barley and rice straw.

In a full irrigation water allocation year, several hundred thousand tonnes of crop residues would be available to convert into biochar in the region.

However, it is recommended that crop residue biochar (CRB) be blended with other lignocellulosic material such as wood waste to make the biochar a more useful product for agriculture. (Singh et al., 2015).

Converting crop residue to biochar also improves air quality and reduces greenhouse gas emissions. Rice straw is currently mostly burnt in the field, which releases various air pollutants including non-methane hydrocarbon compounds and particulate matter (PM2.5 and PM10). The retention of barley and wheat crop residue via conservation agriculture (e.g. crop residue retention via no-till) has reduced the incidence of burning and been found to halt the decline of soil organic carbon (Dr Richard Echart Melbourne University pers.comm. 2022), however the degradation of stubble causes significant release of methane (CH4).

International context

Globally about 4,000 MT/yr of crop residue is produced worldwide from 27 food crops. Rice and wheat contribute around 30% of the global lignocellulosic biomass generation. The degradation of crop residue causes significant release of CH4 as a greenhouse gas, as well as the release of other various air pollutants including particulate matter (PM2.5 and PM10) when burnt.

The detrimental effects of crop residue burning calls for an effective crop residue management system for attaining agricultural sustainability and arresting climate change impacts.

Agricultural expansion has decreased the soil organic matter (SAM); reduced microbial and mesofaunal activities associated with biodiversity loss; increased crop residue burning; and enhanced use of persistent agrochemicals causing human and soil health impacts.

In general, wood cannot be considered as a sustainable feedstock for biochar production in Asian countries that produce enormous quantities of crop residue, particularly rice. However, this region has abundant wood resources as well as crop residues to complement each other for conversion to biochar, thus has the potential for creating a significant number of jobs, improving soil health and agricultural productivity, reducing reliance on agrochemicals (many of which are manufactured overseas and create sovereign risk), reducing GHG's and associated anthropogenic climate change, bioremediation of soil (e.g. PFAS), and reduced air pollution (via reduced crop residue burning).

Potential uses of crop residue biochar for sustainable agriculture

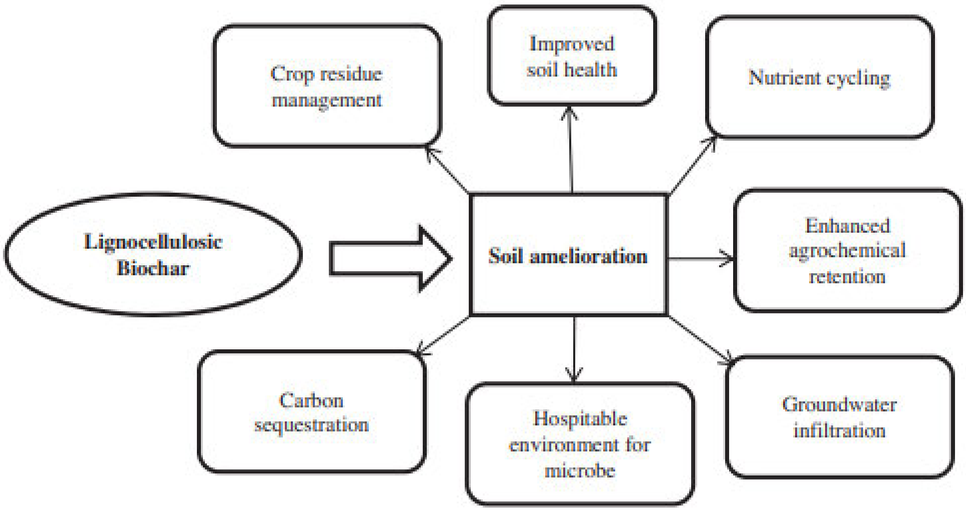
Converting crop residue (CRB) to biochar via pyrolysis has been evaluated as a potential soil ameliorant and carbon sequestration agent. Biochar has been found as a potential soil ameliorant for improving the deteriorating soil quality and has been reported to apply in various ecosystems.

Biochar application to soil has been found to improve soil physical and nutrient profile such as soil C, N and P as like fertiliser, they cause detoxification of soil by adsorbing various contaminants, and provide an hospitable environment to soil biology.

Conversion of biomass carbon (C) to biochar carbon facilitates more C retention in the soil (retains about 50% for a long period of time) of parent C compared to traditional conservation agriculture systems (i.e. burning only retains 3% of the C, with the rest released instantly to atmosphere) and microbial C degradation (10-20% for 5-10 years).

The multifaceted agricultural and environmental benefits of biochar is outlined in Figure 1 below.

Figure 1 – Multifaceted benefits of biochar as soil ameliorant for sustainable agriculture (source Singh et. al. 2015)



Current Trials

There are many unknowns about the conversion of rice straw to biochar via pyrolysis, and concerns have been raised about the composition of rice straw for use in biochar production, in particular its high silica content.

As such Western Murray Land Improvement Group (WMLIG) is sending rice straw to be trialled by a Melbourne company, Earth Systems, using their pyrolysis unit (Charmaker) via funding from the Federal Government's Murray Darling Basin Economic Development Program, and a co-contribution from Murray Local Land Services. The trial will provide:

- Complete basic case study report on conversion efficiency of feedstock to biochar and lessons learned.
- Chemical analysis of biochar emission from stack, feedstock handling, and wood vinegar.
- Basic cost / benefit analysis of producing biochar from rice straw and other by-product options.

This initial trial will be used as a stepping-stone to further explore options for organic waste conversion to biochar in the region, and it is envisioned that a consortia of industry, researchers, government and community group members will join the established biochar cluster group for technical consultation and knowledge sharing and to further scope a range of use options in the future (see Table 1). This can result in a range of benefits and opportunities by:

- Supporting a regionally-based innovation solution to a waste problem that generates products and inputs that can be used for the benefit of agriculture, food and fibre manufacturing, and contribute to regional economic growth and climate change goals. Every regional community generates waste products and needs innovative solutions to improve resource use efficiency and reduce reliance on external farm inputs.
- Delivering the capacity for community, government and industries to respond to emerging climate, water and related changes in business and planning decisions.
- Assist producers here and in other regions (via knowledge sharing) to use waste organics such as biofertilisers to improve soil health and water holding potential, reduce dependence on imported chemicals, and help the community become more self-reliant.
- Provide an opportunity for primary producers to value-add waste organic products (e.g. rice straw and wood waste) via a new value-add income stream providing a buffer against commodity price cycles and climate related issues such as drought.
- Conduct land remediation and rehabilitation, sustainable and profitable regenerative agriculture, rural and regional employment, including substantial multiplier effects in upstream (biomass supply etc) and downstream (markets) industries for businesses in the new carbon economy.
- Opportunities for Indigenous employment as part of land management solutions also present themselves.

Importantly, project outputs can be transferable to any regional community as part of a circular economy.

WMLIG has included the use of wood waste and crop residue conversion to biochar in a One Basin CRC Quickstart Proposal (submitted 9th March 2022) to fund work with a consortia of industry, researchers, government and community groups to scope a range of use options.

Biochar production – the next step

Technologies for biochar production will need engineering, research and infrastructure solutions that provide opportunities for stakeholders/partners to transfer learnings, and intellectual property (IP) to other regions to assist them to respond to emerging climate, water and other emerging issues such as rising input costs.

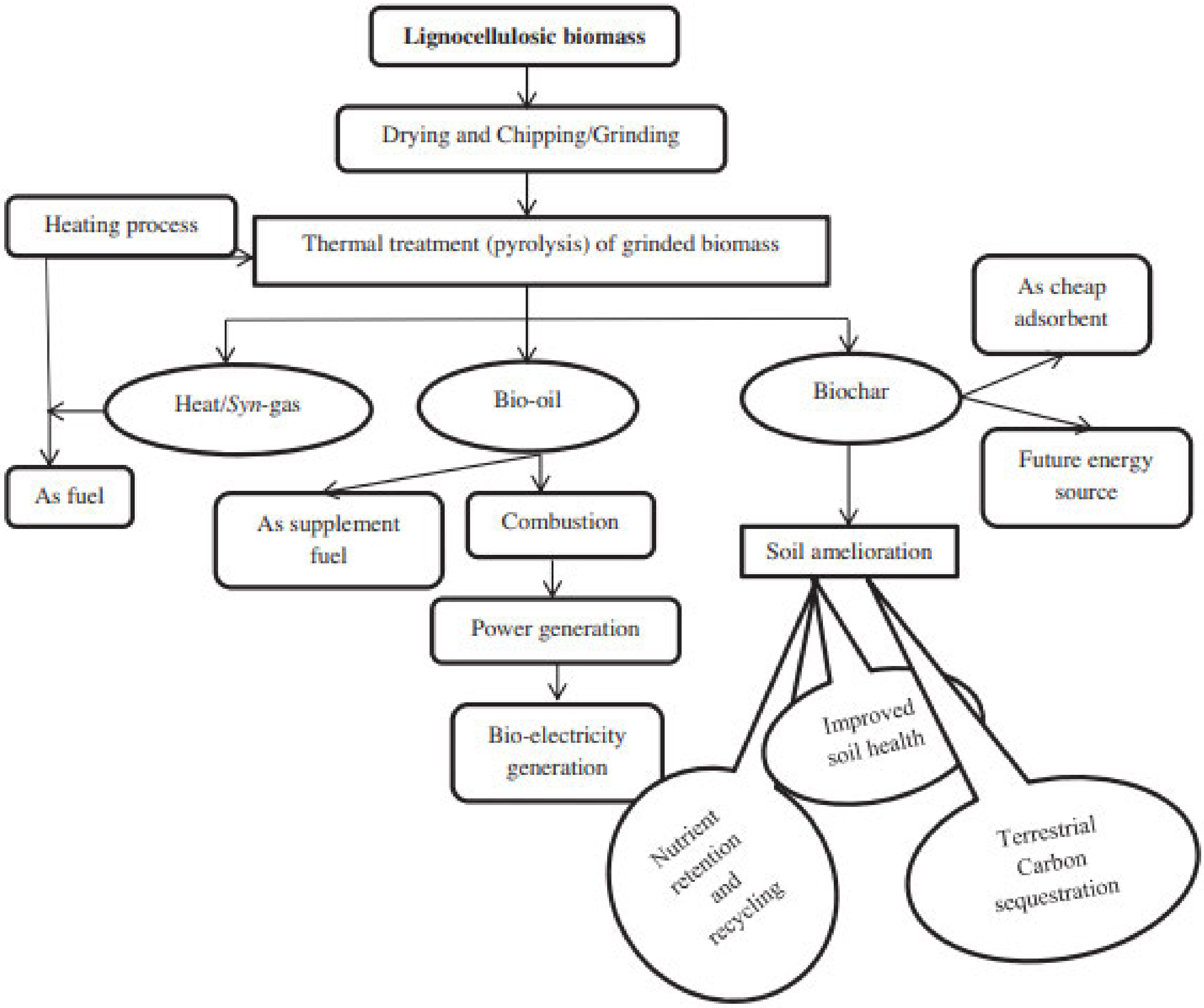
Some off-the-shelf proprietary solutions exist such as pyrolysis units, however the project is seeking to scope a range of other options for novel complimentary projects.

Independent technical advice is needed from researchers and other experienced partners to analyse concepts and provide visibility from salesman and existing IP. The project is looking to integrate technologies and processing ability including biochar production, wood vinegar, biostimulants, biofertiliser, bio-energy / cogeneration. There are opportunities for food and fibre processing (that could utilise waste heat and energy) and hothouse protected habitat plant production for trials or for commercial purposes (this could use waste CO2 in addition to waste heat, wood vinegar for pest and disease control, biochar for growth media addition, biofertiliser and biostimulants as output products from the pyrolysis and biofertiliser production process).

In summary engineering solutions would be required through various concept stages, as well as a blue sky, long term holistic approach infrastructure needs perspective.

Figure 2 below outlines the range of uses of biochar that could create an innovation ecosystem with learnings transferrable to many other regions.

Figure 2 – Sustainable thermochemical conversion process of lignocellulosic biomass to bioenergy and valuable products such as future energy source, cheap adsorbent and soil ameliorating agents (Singh et. Al. 2015)



WMLIG has completed a schematic to illustrate how lignocellulosic biomass from wood waste mixed with crop residue could be used to produce novel biological products in the region (See Figure 3).

Figure 3 – Production of Novel Biological Products

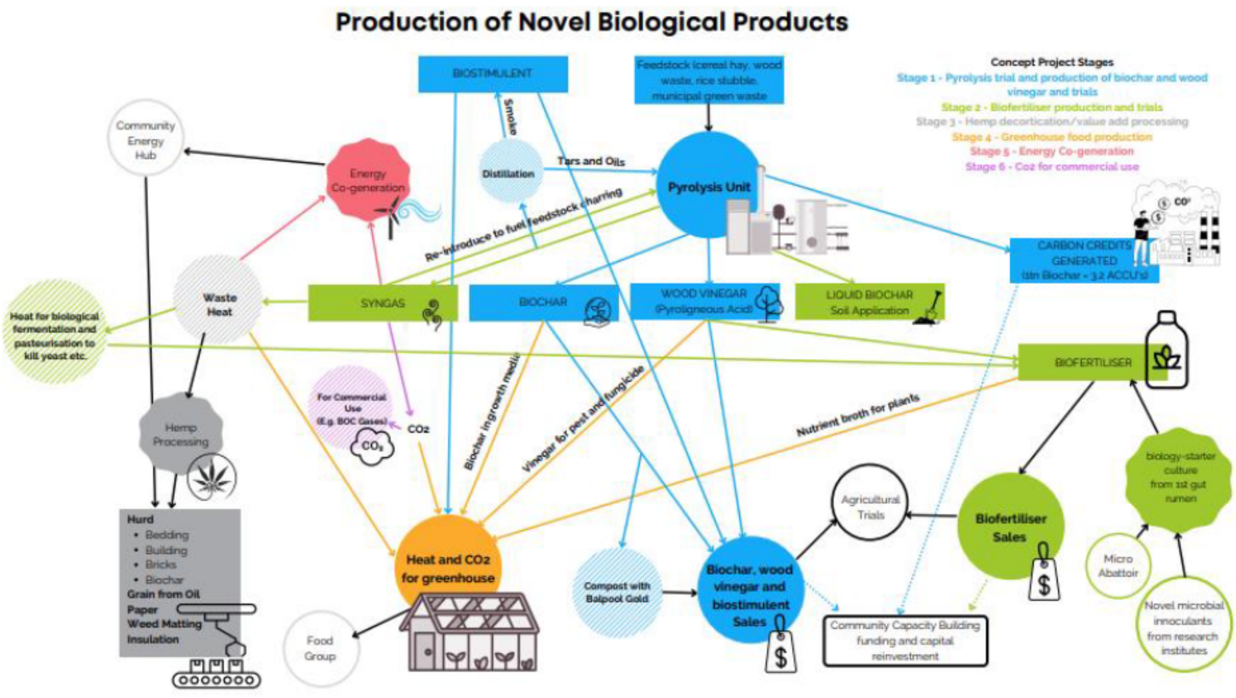


Table 1 below outlines how biochar could benefit a range of stakeholders with outcomes that collectively create a multi-use innovation ecosystem.

Table 1 – Potential multi-use stakeholder association with wood waste / crop residues, secondary novel bi-products and the expected outcomes in a sustainable value chain

User Groups / Organisations	Reason	Expected Outcome
Red Gum Timber Industry	Provision of wood waste as feed stock for pyrolysis process Existing transport and supply chain system Industry knowledge provision	Investment into the project as part of the community investment model. Provision of wood waste for value adding purposes. Conduit for information exchange to the State and Federal Timber Industry Groups.
Industry (e.g. Sunrice / Rice Growers Association, GRDC, MLA, AWI)	To pilot the use of turning industry organic waste products into a valuable resource for agriculture and manufacturing. Value-add current waste organic products, generate additional income, regional jobs and competitiveness. Create new 'green' jobs and secure existing jobs at the community level. Leverage sustainability outcomes for industries in the Basin.	Use the data gathered to apply to future use cases. Commercial partner for product streams arising from the feasibility trials. Establish new sustainable partnerships (practitioners and service providers, placed-based regional partnerships. Linkage to technical experts from isolated research institutions, organisations and agricultural producers).

User Groups / Organisations	Reason	Expected Outcome
	There are human health benefits of reducing the level of Particulate Matter (PM2.5 and PM 10) which are generated through the production of smoke from burning rice straw Improving air quality, and the associated benefits to human health, amenity and activities - forms part of the NSW Clean Air policy, and is a real emphasis of NSW EPA and Dept of Health.	Improved air quality and associated health benefits associated with reduced organic waste residue burning. Investment as part of a potential community investment model Conduit of case study information and alignment to lower carbon footprint products (e.g. rice sustainability platform) seeking higher value added markets from discerning consumers.
Local food and fibre producers and other working group partners	Wood waste utilisation realises opportunities for crop residue waste utilisation. Possibility of farmers employing income-producing add-on processes on-farm, as well as supplying waste material to other manufacturers. Additional income to farmers: • Leverage value chain improvement opportunities, providing additional income to farmers by reducing costs of production and providing value to waste organics, such as rice straw. • Direct farm to market value-add opportunities. Positive farmer backstory leverage for produce access to niche high value markets to discerning buyers.	Improved environmental / sustainability outcomes, opportunity for carbon neutrality, offsetting of GHG emissions (one tonne of biochar sequesters approx. 3.2tns CO2 equivalent) and opportunity to access high value markets from discerning customers. Establish new sustainable partnerships Improved drought resilience for farms: • Improved soil moisture holding capacity - Biochar absorbs up to several times its weight in water. • Reduce input costs associated with chemical fertilisers etc. Improve sustainability outcomes (e.g. soil health, reduce GHG emissions, chemical fertilisers etc.). Reduce environmental impacts and risks associated with chemical/nutrient runoff (biochar is an adsorbent of chemicals) into waterways and agricultural emissions (GHG and air quality). Increase $/ML water returns.
First Nations (e.g. Moama Local Aboriginal Land Council, Joint Indigenous Group)	Provide First Nations employment and Connection to Country as an integral element of the co-design. Provide an income-producing outlet for excess timber deemed to be a risk to the ecological and cultural character of the forest. High coarse woody debris loading creates high fuel loads in the forest and associated risk of wild-fire on culturally significant sites (e.g. birthing/scar trees).	Use the data gathered to apply to future use cases. Establish new sustainable partnerships Opportunities for upskilling and employment of First Nations people in respect to processing timber from the forest estate (e.g. flood runner log jams), and operation of pyrolysis process and associated products.

User Groups / Organisations	Reason	Expected Outcome
	Log jams in flood runners create unnaturally high deposition of sediment in water holes by slowing the flow of water.	A pathway for information exchange between First Nations Groups of Barapa Barapa, Yorta Yorta, Wemba Wemba Nations (JIG)
Irrigated Cropping Council	On ground trials of biochar and other novel biological adjunct with research partners across southern NSW and Northern Victoria (pending alignment to strategic plan review by their Board)	Information sharing amongst partners and members. Establish new sustainable partnerships. Uptake of new / novel biological inputs in irrigated agriculture and future R&D to ascertain cost – benefit analysis of using biological products. Potential new customer pathways for circular economy product outputs.
Murray River Council and other municipal councils in the Basin	Align with Murray River Council's aspiration to 'promote local renewable energy products and implementation of best practices for waste management'. Reduce waste and associated cost implications. The co-design model would link to all levels of government policy on resilience-building. Mitigation of the 'Brain drain' and 'youth drain' from the bush toward larger cities through provision of employment in exciting new green technologies and applications, including many with direct contact (and benefit) for the land.	Provision of green waste for addition to pyrolysis supply chain. Reduce waste and associated cost. Establish new sustainable partnerships Reducing financial costs for food and fibre growers in the region and M-D Basin Rural and Regional employment Demonstrate potential for new business opportunities, while addressing climate change and resilience-building initiatives. Conduit of case study information exchange to State Government and Regional Organisations e.g. RAMJO (Riverina and Murray Joint Organisation of Councils). Funding investment assistance.
General community members	Collaborative community investment to benefit the area by reducing economic leakage from the region. Investment opportunity for local people	Community wealth building/reduced economic leakage from the region. Energy and fertiliser security alternative.
WMLIG	Leverage opportunities created from two existing cluster groups supported by WMLIG.	Diversify income stream to deliver further NRM, ag productivity and community capacity building outcomes.

User Groups / Organisations	Reason	Expected Outcome
	Assist First Nations groups (KP Forest Environmental Project Partners) to reduce coarse woody debris loading and manage red gum wetland encroachment in the local forests. Pyrolysis processes provide an opportunity to utilise wood residue for value-adding and employment. Provide self-supporting income to Western Murray Land Improvement Group (WMLIG), and support WMLIG's mainly farmer member base with improved environmental and agricultural productivity outcomes. The self-supporting income will be generated by managing the governance, logistics, manufacturing, marketing and sale of products (including carbon credits). Educate other Basin communities on cost-benefit analysis of this circular economy model	Opportunities for carbon credits to primary industries using biochar on farms, and or manufacturer investors to offset costs and emissions. Educate other Basin communities on cost-benefit analysis of this circular economy model. Uptake of circular waste conversion initiatives in other regional areas of the Basin Sustainable and profitable regenerative agriculture Land remediation and rehabilitation Create a co-designed pilot program to educate other Basin communities re feasibility of being involved in a circular economy model, learnings regarding the regional collaboration model of the 1BCRC, and environmental benefits of products generated from organic waste conversion. Establish new sustainable partnerships (practitioners and service providers, placed-based regional partnerships. Linkage to technical experts from isolated research institutions, organisations). Assist with agricultural trial research and development.
NSW Government	Reducing the impact of burning organic waste materials improves air quality, and the associated benefits to human health, amenity and activities. This forms part of the NSW Clean Air policy, and is a real emphasis of NSW EPA and Dept Health.	Improved air quality and human health outcomes. Biochar reduces nutrient runoff and associated risk to waterways.
Murray Local Land Services (MLLS)	This project works towards achieving the 2021-2026 MLLS Strategic Plan: Vision: Resilient communities in productive healthy landscapes. Aim: Improving the long-term viability of regional farming businesses and the natural assets that underpin them and	Improved ecosystem health, production and profitability, resilience and adaptation, and grower confidence in long-term viability of farm businesses. Establish new sustainable partnerships MLLS are a conduit of information to other LLS regions in NSW. Case study

User Groups / Organisations	Reason	Expected Outcome
	supporting programs and partnerships that grow primary industries productivity and healthy environments. Contribution of funding for trial work converting rice straw to biochar by Earthtech. Conduit for information exchange to Landholder and State Government networks	information will be valuable for assessment by other Basin Communities with organic waste issues and for agricultural sustainability considerations
NSW DPI	Knowledge of project in other regions in NSW. Case study information will be valuable for assessment by other Basin Communities with organic waste issues and for agricultural sustainability considerations.	Provision of valuable skills and knowledge: NSW have conducted agricultural trials and written scientific papers on biochar production. They have several experts and technical information that will be of value. Assistance with on ground trial work Conduit for information exchange
One Basin CRC (1BCRC) consortia	Learnings associated with impact and commercialisation of 1BCRC investments, developing the outputs of using this framework, channelling strategic focus based on the feasibility studies conducted, the establishment of new partnerships for collaboration with CRC's to use in the future. Provide independent visibility to the community on project opportunities (salesman vs technical experts).	Future CRC investment to use as a Best Practice Case Study (demonstrate value). Establish new sustainable partnerships
Murray Darling Basin Authority	This would be a follow up to the MDBA Commissioned Project, Community Adaptability Engagement Research, Sam Houston State University, 2017 that recommended institutional innovation is required for Regional communities hit hard by the water reform process. *This project focused on enhancing the ability of communities to adapt in response to changes in water management practices, as well as other macro-level changes affecting rural communities across the Murray-Darling Basin. Through the process of institutional innovation, this project examines new strategies for addressing local problems through community-based*	Use the data gathered to apply to future use cases.

User Groups / Organisations	Reason	Expected Outcome
	collective action, bringing stakeholders together to create new local processes to proactively mitigate common challenges.	
Department of Agriculture, Water Resources and Environment	Funded establishment of biochar hemp focus groups and associated field trials, field days and pre-feasibility study as part of the Murray Darling Basin Economic Development Program, for the Wakool Irrigation District.	Investment provided by DAWE is improving triple bottom line outcomes for the Wakool irrigation District
Australian Government	Support Basin communities in dealing with the emerging challenge of adapting agriculture to a changing climate. Begin the vital process of change management for wider adoption of climate-linked practices. Support biochar and bio-sequestration bioenergy technologies as part of the National Bioenergy Roadmap by 2030. The 1BCRC will provide a production line of new research outputs that can be translated worldwide, sustaining Australia's reputation as a leader in water and agricultural research. Connect often isolated regional agricultural communities with limited electronic connectivity to research institutions, organisations, private industry, service providers and government agencies.	Use the data gathered to apply to future use cases and scope start-ups for this region. Establish new sustainable partnerships. Reduce sovereign risk of reputation and reliance on imported products. Critical Action on Climate Change – significant carbon dioxide removal (drawdown / sequestration), not just cuts to continued emissions

Information used for the economic and environmental benefits analysis have been used from a range of sources. Specific examples of scientific trials, applications of use on farm and preliminary results to date from research papers and media articles as examples are outlined below:

Methane reduction for the livestock industry using biochar and sequestration of carbon using dung beetles

Methane is a potent greenhouse gas. It is 80-times more effective at heating the earth than carbon dioxide over the first 20 years following release into the atmosphere.

Biochar is one way farmers are working to reduce the hotly debated environmental impact of cattle. As cows digest their food they release methane - a greenhouse gas more than 25 times more potent than carbon dioxide.

The methane leaves their digestive tract at both ends – through “eructation”, better known as burping, and a small amount through flatulence. Once out of their system, their dung continues to release small quantities of methane.

Ruminant animals have diverse microbial populations in their stomachs that employ anaerobic fermentation to digest feed. Methane is belched into the atmosphere as a by-product of the digestive process. This gut, or enteric methane, primarily from cattle, but also sheep and goats, contributes 30% of the methane released into the earth’s atmosphere each day, and is more than any other single methane source.

A major reduction in methane emissions from ruminants is crucial to preserve ecosystems on the planet (Methane Emissions from Ruminants in Australia: Mitigation Potential and Applicability of Mitigation Strategies Black JL, 2021).

There are more than 1.4 billion cattle in the world today, and together they release 65% of all greenhouse gases from livestock. Efforts to reduce the methane emissions from cows have ranged from vaccines to feeding them seaweed. There is now growing interest in whether by adding another substance to a cow’s diet methane emissions could be reduced: biochar.

In 2012, a research group in Vietnam found that adding 0.5-1% biochar to cattle’s feed could reduce methane emissions by more than 10%, while other studies have found reductions of up to 17%. Studies on beef cows in the Great Plains of the US found that adding biochar to feed reduces cows’ methane emissions by between 9.5% and 18.4%. Given that methane makes up 90% of greenhouse gas emissions from cattle farming, this could considerably cut cattle’s environmental footprint (Mikki Cusack, 7th February 2020 BBC)

Laboratory adsorption trials conducted in California estimated that using biochar for liquid manure treatment could save 57,000 t NH_4 and 4,600 t P_2O_5 fertilizer per year in California alone. It was further shown that feeding 0.3 to 1% biochar could replace antibiotic treatment in chicken and ducks, respectively.

Feeding biochar could thus have an indirect effect on GHG emissions when it is able to replace regular antibiotic ‘feeding’ that produces high indirect GHG emissions after soil application of antibiotic contaminated manure.

Moreover, it was demonstrated that feeding biochar to grazing cows had positive secondary effects on soil fertility and fertiliser efficiency reducing mineral N-fertilising requirements that could be another indirect biochar GHG mitigation effect.

Considering an average C-content of fed biochar of 80% and produced at recommended temperatures above 500°C resulting in H/C_{org} ratios below 0.4, at least 56% of the dry weight of the fed and manure-applied biochar would persist as stable carbon in soil for at least 100 years.

If the global livestock received 1% of their feed in the form of such a biochar, a total of about 400 Mt of CO_2eq or 1.2 % of the global CO_2 emissions could be compensated. The apparent potential for improving animal health and nutrient efficiency, for reducing enteric methane emissions as well as GHG emissions from manure management and for sequestering carbon with soil fertility improvements makes it compelling to increase the scientific effort to investigate, measure and optimize the GHG reduction potential of biochar use in animal farming systems. (Using biochar in animal farming to recycle nutrients and reduce greenhouse gas emissions (Schmidt et al 2017)

The average specialist beef producer in Queensland has 1158 head of cattle (ABARE 2000) which emitted 103 tons of methane per year. This is equivalent to emitting 2,163 tons of carbon dioxide each year. (ECONOMICS OF REDUCING METHANE EMISSIONS FROM CATTLE PRODUCTION IN CENTRAL QUEENSLAND, Rolfe J. 2001). This equates to 1.87 tonnes CO_2 per cow /yr.

Whole-farm biochar system boosts productivity, stores carbon, cuts inputs and emissions.(Lauren Celenza, WANTFA Extension Manager, 2015)

Western Australian example of using biochar and sequestration of carbon by dung beetles

How to feed cows biochar?

Surprisingly, it's not difficult to train a cow to eat something they don't normally eat.

Rewarding them with something sweet is how West Australian farmer, Doug Pow, gets his stock to eat biochar, mixing it with molasses or glycerine and presenting it in a feed trough or bucket. Doug says the cows will eat a few mouthfuls and then move onto pasture, allowing others to ingest the sweet black sludge, regardless of their ranking in the herd. Doug feeds approximately 300g of biochar per cow per day.

This figure was developed from research into intensive dairy operations in Germany to reduce diseases caused by housing, hard floors and ammonia being released from the dung. "Once the dung has the incorporation of biochar into it, it seems to absorb a lot of the nitrogen and doesn't volatise into ammonia, which is what causes the health problems, but luckily the lack of smell hasn't deterred the dung beetles", Doug said.

Biochar and Animal Husbandry

(by Cyclic Carbon November 05, 2020)

The use of biochar in animal husbandry continues to be a key source of interest among researchers and its application is signalling an effective, non-invasive and low-cost strategy that could markedly improve the sustainability and outcomes of animal husbandry and farming more generally.

Expanding research continues to shed light on the various intricate mechanisms by which biochar interacts with gastrointestinal and broader metabolic processes in livestock and their products, and the real-world environmental and economic implications of biochar used in animal husbandry more broadly.

Schmidt et al. (2019) published an extensive review covering the current state of published research on the topic:

- **The use of biochar in animal husbandry is a common practice**
  The use of biochar in animal husbandry is in common use and there is evidence that the application of biochar as an animal feed additive and curative has occurred for millennia.

  In the case of modern management techniques, biochar is increasingly being adopted in animal husbandry as it gains recognition for a range of on and off-farm benefits, particularly in Europe and Australia. Currently in Europe, the largest end-user of industrially produced biochar is as an additive in feed, bedding and manure treatment (Schmidt et al., 2019).

- **Biochar as a feed additive**
  As a feed additive, biochar is shown to increase nutrient uptake and improve the overall feed efficiency and the feed to weight ratio for livestock. Further, biochar helps control gastrointestinal pathogens and reduces methane emissions from livestock.

  Schmidt et al. (2019) provides and overview of the results of 27 individual peer-reviewed studies investigating biochar as an animal feed additive ranging from feed for cattle, poultry, goat, sheep, pig and aquaculture with feed rates ranging from 0.2-4% (weight) of livestock basal diet.

- **Biochar as a feed supplement for cattle**
  In cattle, biochar in feed was reported—by surveyed farmers using the practice—to improve the overall health and vitality of animals. Harmful bacteria measured in the milk (as the somatic cell count) of biochar fed cattle was indicated to decrease significantly. Farmers also reported a decrease in hoof problems, greater postpartum health, reduced symptoms of diarrhoea, an overall decline in mortality rates and a decrease in associated veterinary costs (Schmidt et al., 2019; study from *Gerlach and Schmidt, 2012).*

  Biochar was shown to increase live weight and feed efficiency in cattle fed at a rate of 1% by weight of basal diet, with one trial indicating a 31% increase in feed conversion rate using biochar as a feed additive alone, and a 60% increase in feed conversion rate when biochar was enriched with a rice wine distillery (fermented) byproduct. This compares to an 18% increase in feed conversion rate when animals were fed the fermented wine byproduct alone (Schmidt et al., 2019, study from *Phongphanith and Preston, 2018*).

  The above findings indicate that even relatively small supplementation of biochar can result in disproportionately enhanced growth benefits. Additionally, by combining biochar into diets with other beneficial feed additives enhances the outcomes of both amendments.

Disclaimer: More detailed research needs to be undertaken to evaluate a range of soil types, using different biochar types, biochar/molasses ratios, and dosage rates and dung beetles species. There is a need to analyse accurately costs and benefits to the farmer and also the feasibility of this method for long-term sequestration of C into soils. Further tests need to be carried out to determine if there are any residual toxins, such as polycyclic aromatic hydrocarbons or dioxins, which have accumulated in the meat of the cattle (Joseph et al. 2015).

Appendix A

Case Study 1 – Utilisation of wood waste and dairy manure for compost.

O'Neill's Dairy and Avocado Orchard

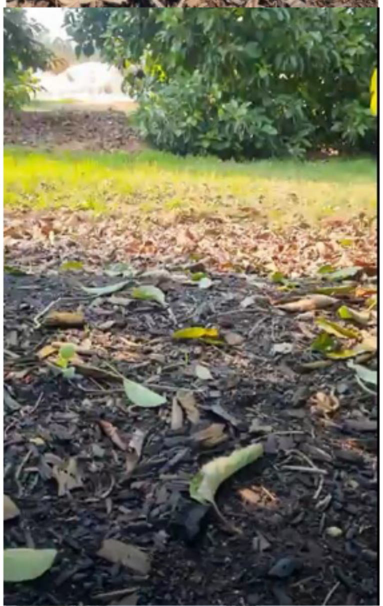
Dairy: 500 cows

Orchard size: 30Ha, 8,500 avocado trees

Waste red gum timber residue is valued as a primary feedstock in a novel approach to producing compost for avocado trees. Avocado Farm Manager, Sam Chapman, says locally sourced red gum waste residue is mixed with cow manure from the farm dairy operation, with biological cultures added to mineralise source material and make it more plant available.

The manure is not officially composted but has been turned several times and is approximately one year old or more before application. Previously this was applied as a mulch mix of @1 part manure/2 parts redgum mulch. This mix is now @ 1 part manure / 6 parts redgum mulch.

In spring a proprietary biological product known as Metagen Digestor NP is applied via fertigation and driplines to the mulch. Digestor NP is microbially formulated to improve crop and soil health, yield and production quality by improving nutrient availability, nitrogen cycling and phosphorus release. Other benefits include improving soil structure, rooting depth, water infiltration and water holding capacity. It brings whole system gains.



In Autumn, another proprietary biological product called CataPult SuperFine is applied onto the mulch. CataPult SuperFine contains Mycorrhizae (VAM) and Bacillus. The product improves P nutrition in crops collects N, Zn, Ca and several other nutrients very efficiently and transports them back to the crop plant via the mycorrhizal hyphae. This improves feeder root mass, nutrient uptake and reduces root-based disease, particularly Phytophthora.

Soil health contributes to fruit quality, size, and fruit robustness. Avocados have a great pack out rate, which reduces waste and provides access to premium markets.

If wood waste was no longer available, Sam said he would have to use some type of straw. The straw requires specific machinery to break it down and apply and does not have the service life of wood waste or the same micro and macro nutrient composition.

Mushrooms have been observed to voluntarily grow on the mulch in the avocado orchard, and there maybe an opportunity to grow specific commercially significant species as a business diversification option in the future.

Appendix B

Biochar boosts Fleurieu dairy production (Stock Journal 7th Jun 2020)

INCLUDING biochar in dairy feed mixes has led to a marked increase in milk yield during trial work on the Fleurieu Peninsula, and its effects are set to be investigated in beef herds.

In research conducted by Climate and Agricultural Support Group's Melissa Rebbeck and funded by the Dairy Industry Fund, a hardwood-based biochar was added to a dairy herd's feed mix at a rate of 150 grams a head per day.

Across a year, one dairy trial showed an improved milk yield of 1.4 litres/head/day on average.

Ms Rebbeck said biochar was sourced from NSW for the trials at $800 a tonne, with a total cost of $11,000 for the year.

"The increase in profit from increased milk yield worked out to about $70,000 for the year, taking into account the cost of the biochar," she said.

"We're looking to get biochar produced locally and hoping to keep the cost under $300/t."

Ms Rebbeck said despite the increased milk yield, the trial's dairyfarmer noticed his cows required less fodder.

"He was feeding two round bales less a week for 250 cows, which equates to about $12,000 of savings a year just in fodder," she said.

The astounding trial results were credited to improved feed conversion, stemming from a redox reactive process in the rumen.

"I buy my cattle from markets to fatten and sell," she said. "I get them onto biochar straight away and have noticed a marked improvement in behaviour, manure smell, coat shine and they fill out reasonably quickly."

While the increased milk yield and fodder savings shown during the dairy trials were impressive, a co-existing dung beetle breeding program has amplified the trial's success by helping to positively impact soil and plant health.

Creation Care's Greg Dalton, owner of a Strathalbyn dung beetle breeding facility, has worked with Fleurieu Beef Group and Dung Beetles Solutions' Bernard Doube to breed and release winter and summer active beetles over the past decade.

FBG has seen multiple soil health and production benefits as the beetles have populated the Fleurieu.

BEETLES AMPLIFY FEEDING RESULTS

CREATION Care's Greg Dalton has now imported, bred and released three species of spring active dung beetles on 40 properties across the Fleurieu.

Climate and Agricultural Support's Melissa Rebbeck said the beetles had quickly multiplied and would soon be released to infiltrate other Fleurieu farms.

"Dung buried from cows on the biochar feed is carbon and mineral-laden and we have anecdotal evidence that it builds soil microbes, carbon and soil health," she said.

"We're conducting additional replicated trials to further measure and publish this work.

"When talking manure content, 250 cows produce 2000 tonnes of dung in a year. If that's buried by dung beetles - an average property on the Fleurieu might be 200 hectares - it equals 10t/ha of cow manure full of beneficial minerals and carbon.

"It is a rate far higher than what can be afforded spreading other fertilisers, which are often spread at a maximum of 200kg/ha.

"Spreading 10t/ha of cow manure that's been activated with biochar could have big benefits to soil, profitability and production."

At a dairy hosting a biochar feed trial with active populations of dung beetles, Ms Rebbeck said there had been one unit of pH increase in its acid soils in just nine months.

They also found an increase in cation exchange capacity - better nutrient and mineral take-up by plants - and more potassium and calcium in plant tissue.

Appendix C

Conceptual Pyrolysis Opportunity

Converting wood waste and crop residue to biochar / wood vinegar with carbon credit potential/yr for 23 pyrolysis units			
Summary Costing wood waste only			
Item	**$ Return (conservative) /yr**	**$ Return (Average) /yr**	**$ Return (High End) /yr**
Output			
Biochar	$ 8,500,000.00	$ 29,750,000.00	$ 51,000,000.00
Wood vinegar	$ 3,966,666.67	$ 4,958,333.33	$ 5,950,000.00
Total	**$ 12,466,666.67**	**$ 34,708,333.33**	**$ 56,950,000.00**
Carbon Credits CO2 from biochar	$ 1,530,000.00	$ 3,825,000.00	$ 6,120,000.00
CO2 equivalent methane reduction (CC above x 1.28)	$ 1,958,400.00	$ 4,896,000.00	$ 7,833,600.00
Total	**$ 3,488,400.00**	**$ 8,721,000.00**	**$ 13,953,600.00**
Subtotal	**$ 15,955,066.67**	**$ 43,429,333.33**	**$ 70,903,600.00**
Net Return (after labour, feedstock cost etc.)	**$ 8,683,386.67**	**$ 36,157,653.33**	**$ 63,631,920.00**
Note that livestock productivity benefits, job creation and infrastructure flow on benefit economics have not been included in the benefits analysis			

Production based on a pyrolysis unit operating 6 hours day, 5 days a week = 3 tonnes per day or 15 T /wk.

<u>Calculation assumptions:</u>

Biochar and bio vinegar sales:

- Biochar sales of $500 - $3,000 per tonne
- Wood Vinegar as above operation times = 350 Litres per day or 1,750 litres per week @ $2000-$3000 per 1000 Litres
- Potential income on sales = $7,500 – $45,000 Biochar and $3,500 – $5,250 Wood Vinegar - Total $12,000 – $50,500 per week

<u>Carbon credits:</u>

- Australian carbon credit units (ACCU's) are currently attracting between $30-50 per tonne of CO2 equivalent on govt and voluntary carbon markets. A high end value of $150 / ACCU was used as the high end figure.
- 1 tonne of biochar is equivalent to offsetting 3.37 tns CO2 equivalent. A figure of 2.5 was used as a conservative estimate taking into account mix with crop residue biochar which has a lower CO2 equivalence value.
- A livestock feed additive methane reduction factor of 1.28 x biochar CO2 carbon credit was used based on 20% of biochar availability being used for feed additive.

References:

Mikki Cusack, BBC, 7th February 2020 Can charcoal make beef better for the environment?

Cyclic Carbon November 05, 2020. Biochar and Animal Husbandry

El-Hadal M.E. et. al. Nematidal effects of bacterial biofertilisers. Brazilian Journal of Microbiology. 2010

Gerlach A, Schmidt HP. 2012. Pflanzenkohle in der Rinderhaltung (translated as "Biochar in cattle farming"). Ithaka Journal1:80-84, English translated version access via: http://www.ithaka-journal.net/pflanzenkohle-in-der-rinderhaltung?lang=en.

Kariman, K. Biofertiliser potential in native fungus. GRDC Groundcover. Jan – Feb 2021

Joseph. S. et al. / Science of the Total Environment 724 (2020) 138153. Biochar increases soil organic carbon, avocado yields and economic return over 4 years of cultivation. 2020.

Lin Xu and Danny Geelan. Developing biostimulants from Agro-food and Industrial By-products. Frontiers in Plant Science 2018.

Phongphanith S, Preston TR. 2018. Effect of rice-wine distillers' byproduct and biochar on growth performance and methane emissions in local "Yellow" cattle fed ensiled cassava root, urea, cassava foliage and rice straw. Livestock Research for Rural Development 28:Article #178.

Rolfe J. 2001. ECONOMICS OF REDUCING METHANE EMISSIONS FROM CATTLE PRODUCTION IN CENTRAL QUEENSLAND,

SEGRA, The social and economic value of country-based community service organisations, 2019

Schmidt, H.P., Hagemann, N., Draper, K. and Kammann, C., 2019. The use of biochar in animal feeding. PeerJ, 7, p.e7373.

Schmidt et al 2017. Using biochar in animal farming to recycle nutrients and reduce greenhouse gas emissions

Singh P. et. al., Multifaceted application of crop residue biochar as a tool for sustainable agriculture: An ecological perspective. Ecolical Engineering. 2015.

Sustainable Economic Growth for Regional Australia (SEGRA 2019)

Stock Journal 7th Jun 2020. Biochar boosts Fleurieu dairy production

Yousseff M.M.A and Eissa M.F.M. Biofertilisers and their role in management of plant parasitic nematodes. A review.2014.

Winders TM et al 2019, Evaluation of the effects of biochar on diet digestibility and methane production from growing and finishing steers