November 2024

Towards a Circular Economy and Net Zero Through Carbon Stewardship

A joint submission prepared by SEATA Group, the Global Product Stewardship Council, and Catalyst Environmental Management.

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Introduction

Addressing Requirements of the Inquiry

Thank you for the opportunity to provide this submission to the Productivity Commission's Inquiry into *Opportunities in the Circular Economy*. As required by the guideline for the call for submissions, our document includes information to address (but is not limited to) the following:

(i) **Circular Economy Success Stories and Measures of Success** *(Info Request #1)*

(ii) **Priority Opportunities to Progress the Circular Economy** *(Info Request #2)*

(iii) **Hurdles and Barriers to A Circular Economy** *(Info Request #3)*

(iv) **Government's Role in the Circular Economy** *(Info Request #4)*

Accordingly, our joint submission follows this format/structure. Given the opportunities highlighted in our submission are relatively 'new' (or unaware) to many in the broader community and government, our submission also provides detailed information introducing and explaining circular carbons and carbon stewardship for circular economy. Additionally, our submission provides multiple appendices and further supporting information to help justify the submission's 'calls to action' for government support toward this vitally important industry in order for it to reach its potential to contribute significantly toward positive economic, environmental and social outcomes for Australia in both regional and urban areas, and across multiple industry sectors throughout the economy. We would welcome the opportunity to meet with the Productivity Commission to discuss these significant opportunities further.

Joint Submission Partners:

Global Product Stewardship Council

Catalyst Environmental Management

SEATA Group

About Us

Global Product Stewardship Council (GlobalPSC) is an independent, not-for-profit forum helping to facilitate the implementation of product stewardship and extended producer responsibility (EPR) programs globally, reducing the impacts of products on the environment throughout their lifecycle, including more efficient resource and energy use, and less pollution. GlobalPSC members includes producers, product recovery organisations, re-processors, NGOs and governments at federal, state and local levels.

Catalyst Environmental Management (Catalyst) is a specialist environmental consultancy and GlobalPSC member dedicated to delivering tailored services that enhance environmental stewardship, reduce risks, and ensure regulatory compliance. Catalyst is committed to supporting responsible development and advancing sustainable practices through science-driven strategies and collaborative partnerships.

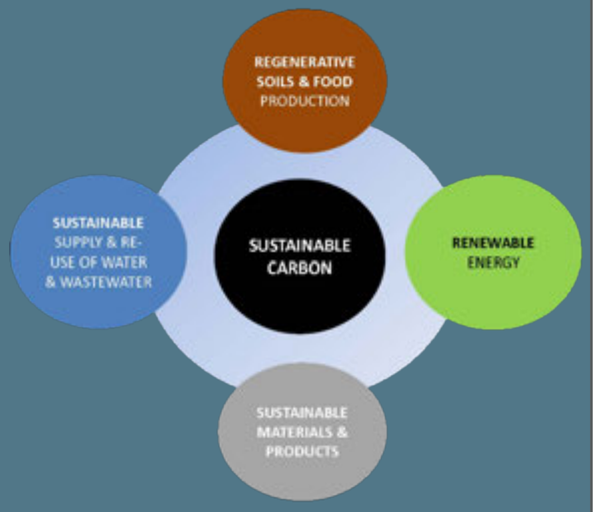
SEATA Group (SEATA) has developed a new advanced thermal technology (currently at field pilot in the New England Renewable Energy Zone in NSW) designed to produce high quality biochar and concentrated high grade syngas capable of producing valuable derivatives such as carbon negative hydrogen and circular fuels, at commercial and industrial scales. A single 5 tph (dry infeed) SEATA plant is designed to provide the equivalent of the entire 2025 hydrogen target set by the NSW Government (3,000 tpa), along with all the co-benefits of biochar. The technology is designed for industrial scale up to 40 tph infeed (8-40x larger than conventional pyrolysis plants for biochar to date), and in theory can provide significantly larger capacities. This could provide a genuine renewable and sustainable alternative superior to conventional large combustion and incineration for baseload energy, at a fraction of the cost and with many environmental, economic and social benefits.

Our joint submission has been informed by engaging with the broader biochar bioenergy industry extensively over a number of years. Representatives from SEATA, GlobalPSC and Catalyst are very active within the **ANZ Biochar Industry Group (ANZBIG)** and have played central roles in the development of the **Australian Biochar Industry 2030 Roadmap** (ANZBIG, 2023) (ANZIBIG 2030 Roadmap).

Introduction and Background – Circular Carbons

Carbon plays a key role in the food-energy-water nexus (**Figure 1**). Carbon is the building block of all life and for many of the things we make and use. Displacing production of *new/additional* fossil carbon with more sustainable circular carbons (e.g. biochar and other chars) can help decarbonise the economy.

Figure 1: The Carbon Nexus



> *We need to remove the excess carbon from the sky and bring it back down into our soils and materials where it is needed most.*

Circular carbon processes present **significant** opportunities to ***upcycle*** otherwise wasted resources to *higher order uses,* as outlined further throughout this submission, including **examples of commercialised applications**.

Circular carbons can be generated across ***all three** physical phases* – **solids** (e.g. biochar), **liquids** (e.g. wood vinegars, circular fuels) and **gases** (e.g. biogas / syngas) (refer **Figures 2,3**). However (and importantly), these can generally be divided into two distinct groups in terms of their **additional role and relevance for *climate action***:

(i) **Biogenic Circular Carbon –** made from solid biomass (organic material) that has captured carbon from atmosphere in the current natural carbon cycle. For example, *biochars* which (specifically) differ from other biogenic circular carbons by their unique and important characteristic of providing *long-term* atmospheric CO_2 Removal (CDR) as outlined further in the following section.

(ii) **Fossil-Based Circular Carbon** – made from wastes originally produced from fossil-based carbon (coal, oil, gas) that is **not** part of the current natural carbon cycle (e.g. plastics, tyres etc.).

These are outlined further in the following sections, with a focus on *biogenic* carbons.

Figure 2: Circular Carbon (Solids, Liquids and Gases) from biogenic infeeds for Renewable Energy, Circular Fuels & Drawdown (CDR)

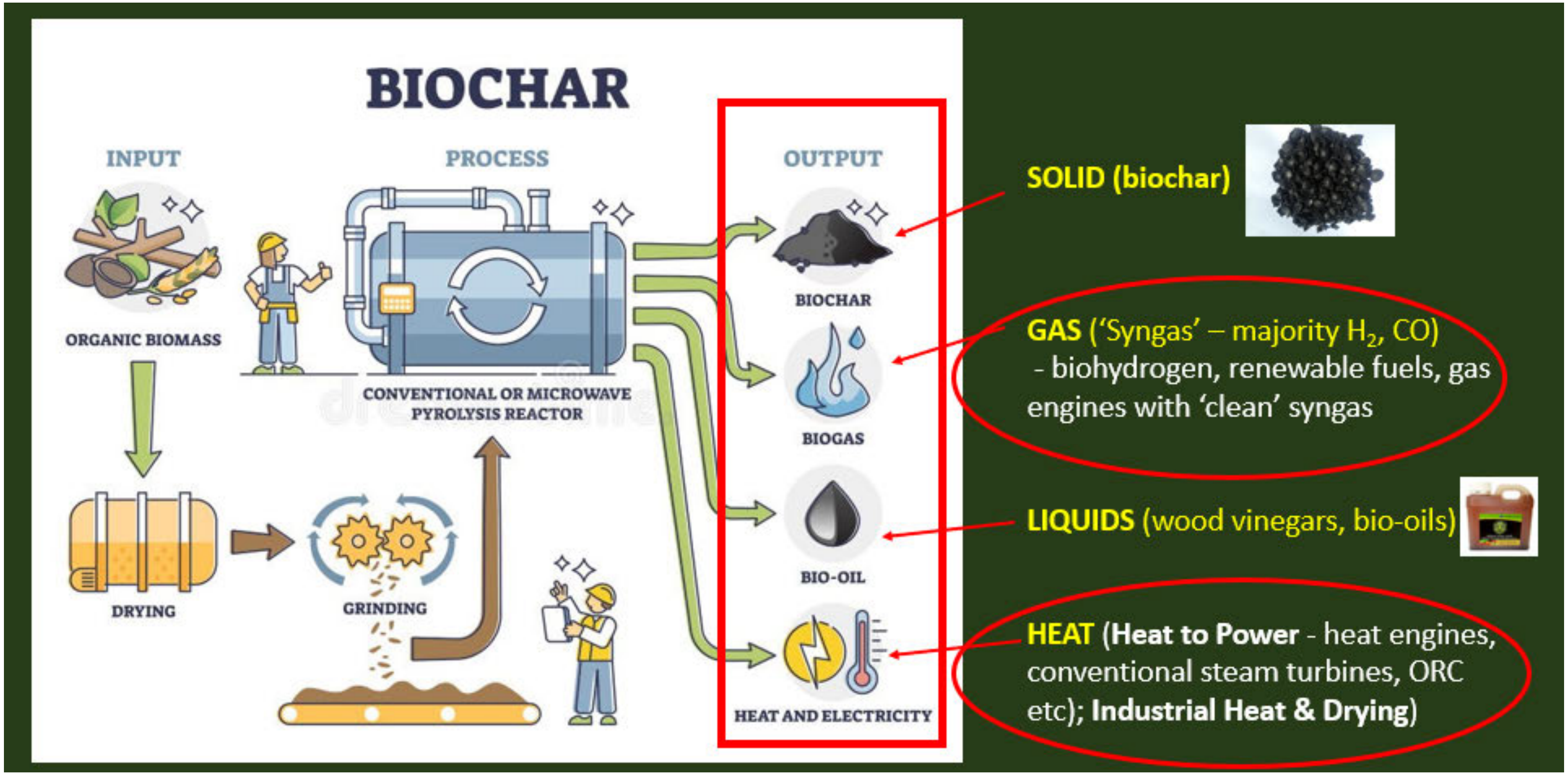
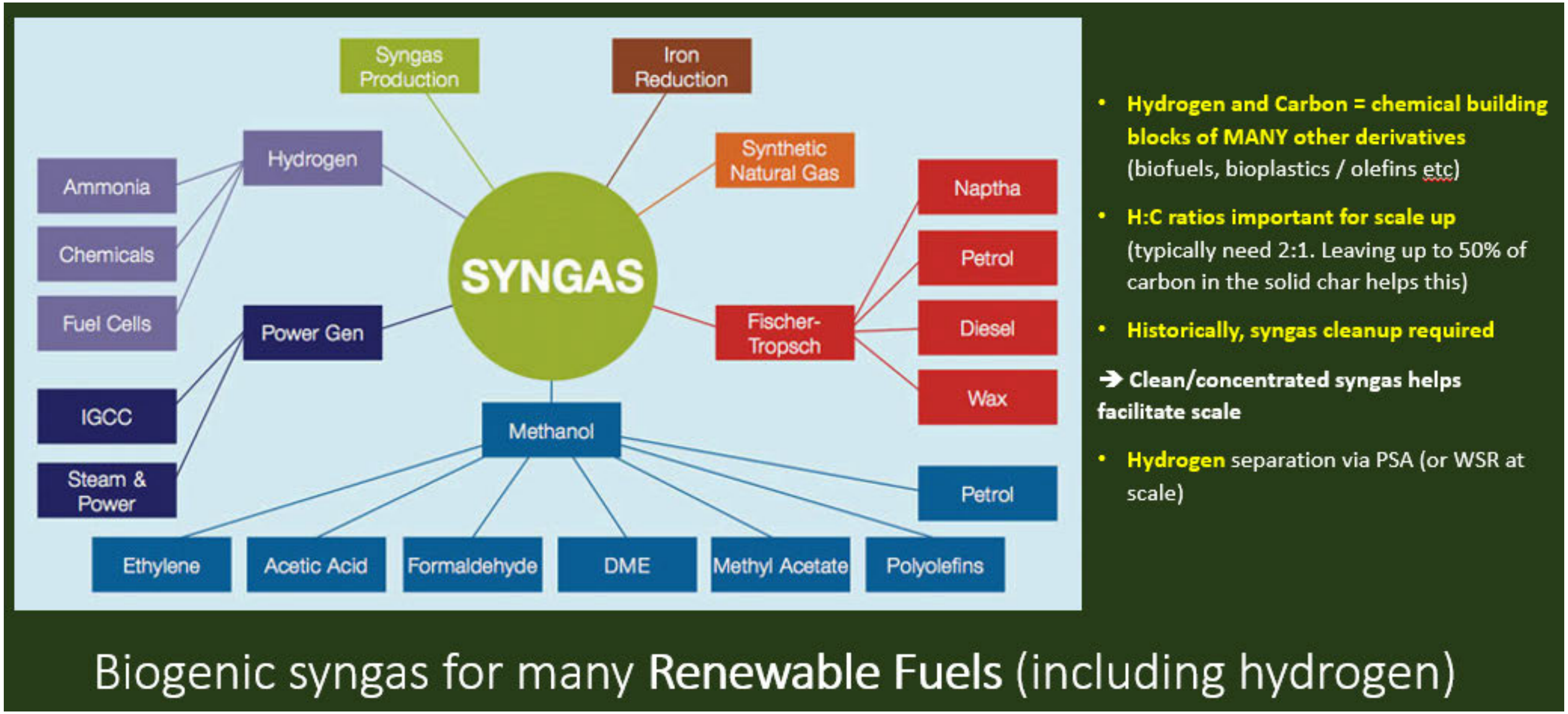


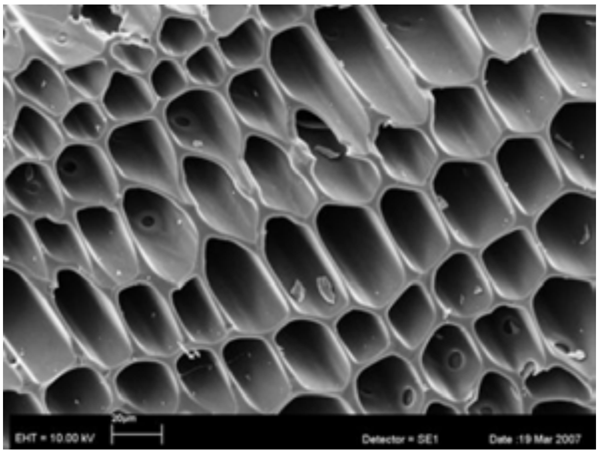
Figure 3: Syngas: Electricity *and <u>much</u> more - Biogenic syngas for renewable fuels (including biohydrogen)*


Syngas Production
Iron Reduction
Hydrogen
Synthetic Natural Gas
Ammonia
Chemicals
Fuel Cells
SYNGAS
Power Gen
IGCC
Steam & Power
Fischer-Tropsch
Naptha
Petrol
Diesel
Wax
Methanol
Petrol
Ethylene
Acetic Acid
Formaldehyde
DME
Methyl Acetate
Polyolefins
Hydrogen and Carbon = chemical building blocks of MANY other derivatives (biofuels, bioplastics / olefins etc)
H:C ratios important for scale up (typically need 2:1. Leaving up to 50% of carbon in the solid char helps this)
Historically, syngas cleanup required
➔ Clean/concentrated syngas helps facilitate scale
Hydrogen separation via PSA (or WSR at scale)
Biogenic syngas for many Renewable Fuels (including hydrogen)

(i) Biogenic Circular Carbons (e.g. Biochar and Biocarbon)

What is Biochar?

Biochar is *"a carbon rich, charcoal-like product made by heating any form of organic matter (biomass) in a controlled process with limited oxygen. This product is called "biochar" when it is used as a soil amendment or for other uses that store the carbon in a durable form"* (ANZBIG, 2023).[1]



How is Biochar made and what other Co-Products & Co-Benefits does it bring?

Heating materials progressively changes physical phase into solids, liquids and gases. Subsequently, modern commercial pyrolysis and gasification processes typically produce two or more products across these phases. Typically up to 1/3 of the biomass feedstock is converted to solid biochar *in pyrolysis*, with the remainder reporting to liquids and/or gas ('syngas') products, as illustrated in **Figure 2**.

Pyrolysis and gasification processes also create a potentially **valuable gas co-product called *syngas*** ('synthetic gas')**,** typically comprised primarily of H_2 and CO (and minor gases) when produced in a pure process (such as SEATA's) or via further refining ('cleanup'), which can be either used directly for on-demand renewable energy, or further processed into a range of syngas derivatives including green hydrogen and food and medical grade CO_2 (to displace fossil CO_2), biomethane (renewable natural gas, rNG) and a range of high value ***circular fuels,*** as illustrated in **Figures 2,3**. This further displaces fossil carbon (via 'gas to X' pathways) for additional critical climate action.

[1] A Fact Sheet is available *here* and link to a brief introductory video "What is Biochar?" provided *here*.

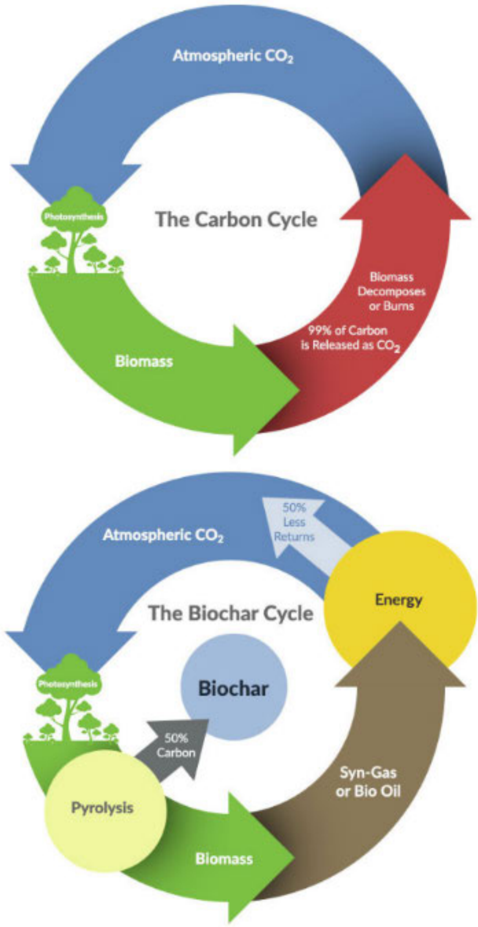
As such, **biochar bioenergy systems generating biochar and syngas can concurrently aid *both* critical elements required for climate action toward Net Zero: ER *and* CDR.**

Sustainable biochar production is a powerful tool that is being recognised globally for its potential to produce clean renewable energy, sequester CO_2 from the atmosphere, improve soil health, and support sustainable agriculture. The circular carbon and low-climate footprint of biochar can be used to displace fossil carbon currently used in a wide range of industries across the economy, with scores of fully commercialised soil and non-soil/industrial applications already available here and overseas, from supplements to minimise synthetic fertilizer use through to water filtration, roads, bioplastics and concrete among many others. These are outlined in the *Australian Biochar Industry 2030 Roadmap*, launched in June 2023 by the ANZ Biochar Industry Group (ANZBIG), which represented a world-first for the biochar industry. ANZBIG is patroned by renowned economist Professor Ross Garnaut who provides a forward to the Roadmap. A copy of the roadmap is provided in **Appendix 1** to this submission. .

The biochar industry is poised to play a vital role in sustainable land use and the circular economy. The Australian Biochar Industry 2030 Roadmap outlines the steps needed to scale the biochar industry to a multibillion-dollar sector, highlighting the significant potential to displace fossil carbon used in a wide range of materials and uses across the entire economy in both soil and non-soil/industrial applications, and make potentially significant contributions toward national and state decarbonisation and circular economy goals.

With more uses for biochar emerging, **the global biochar market is growing and is estimated to be worth $USD 3.82 billion by 2025**. Potential and existing biochar industries in Asia, the US and Europe are rapidly expanding. As an important indicator of global leadership in this direction, the government of Denmark reportedly has allocated **USD$1.35 billion specifically to accelerating the biochar industry in Denmark** and has released its biochar strategy, similar to the existing Australian Biochar Industry 2030 Roadmap, which notably has not received any external funding at all yet, and is understood to be seeking a fraction of that provided in Denmark. The Danish strategy forms part of its goal to save 1.8Mt CO_{2e} in agricultural emissions by 2030. Supportive policies for biochar have also been adopted within: the EU's recent Trilogue on Carbon Removal Certification Framework (CRCF); the USDA's Soil Carbon Amendment Code and associated financial assistance program; and the Swiss 'CDR Roadmap' for CCS and Negative Emissions Technologies (NETs).

Figure 4: Biochar intercepts the carbon cycle to remove CO_2 (CDR). *Biochar is one of the handful of Negative Emissions Technologies recognised by the IPCC for CDR.*



Over 99% of CO_2 captured by plant biomass re-enters our atmosphere as part of the natural carbon cycle.

Pyrolysing excess wasted plant biomass into biochar **intercepts the cycle** and converts carbon into a **solid form** that is typically **stable for centuries to millenia**.

*"The **deployment of CDR** to counterbalance hard to abate residual emissions is **unavoidable if net zero** (CO_2 and total GHG) **is to be achieved**."*

IPCC 6th Assessment Report April 2022

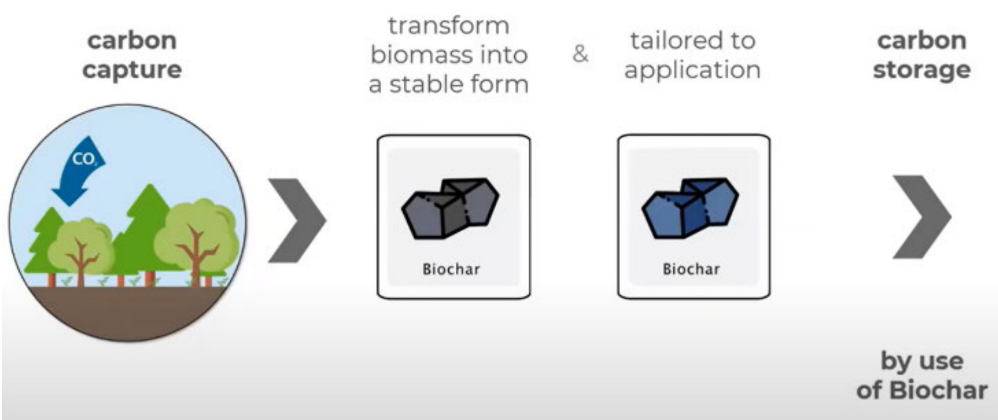


Figure 5 (Above): **Biochar CO_2 Removal (B-CDR, or BCR)**

Capturing carbon, valuably using *<u>and</u>* *storing it in the long term.*

Figure 6: Biowastes for Circular Carbon (biogenic carbons including biochar)

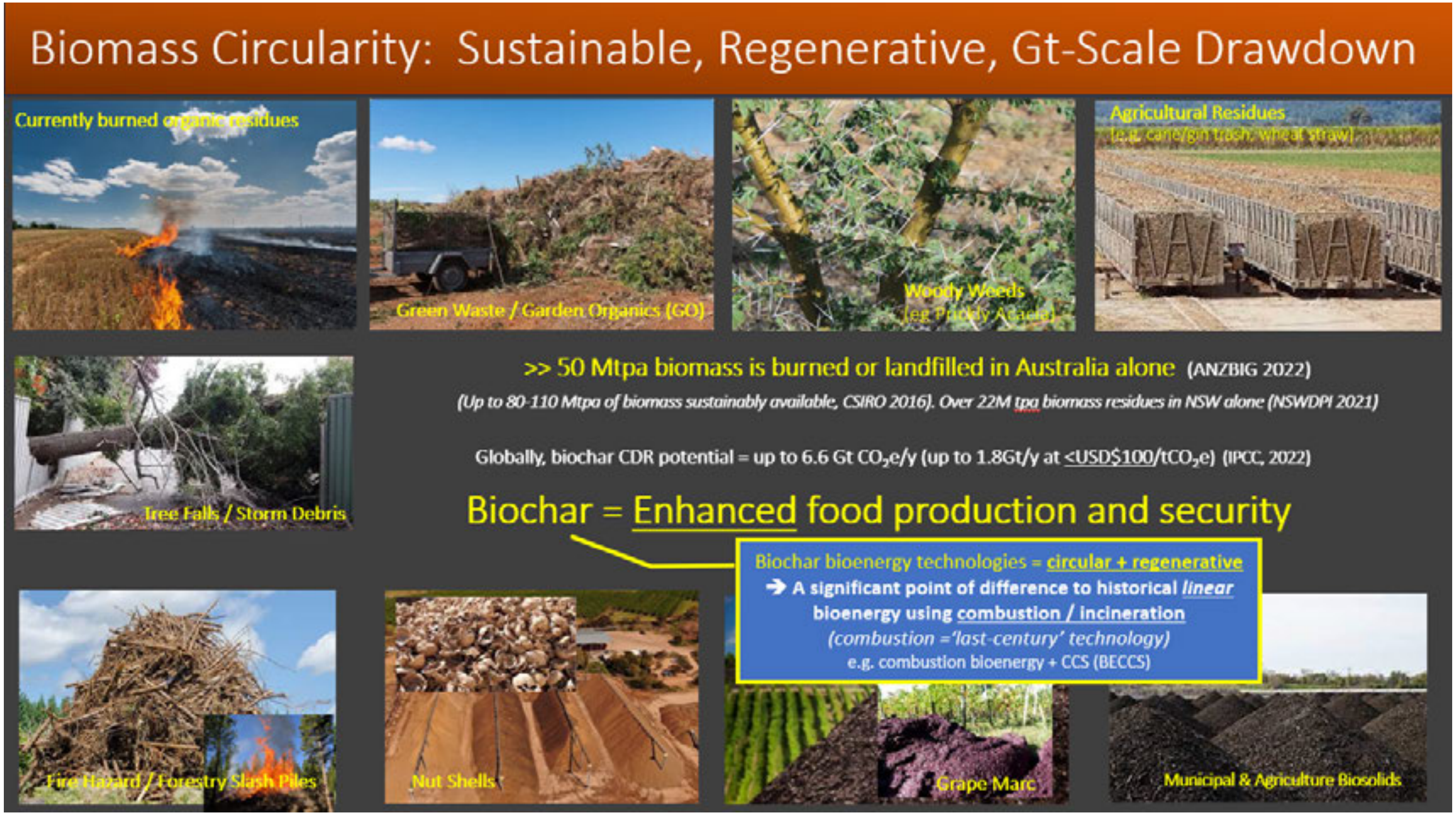


Figure 7: Urban and Rural Soil Applications for Biochars

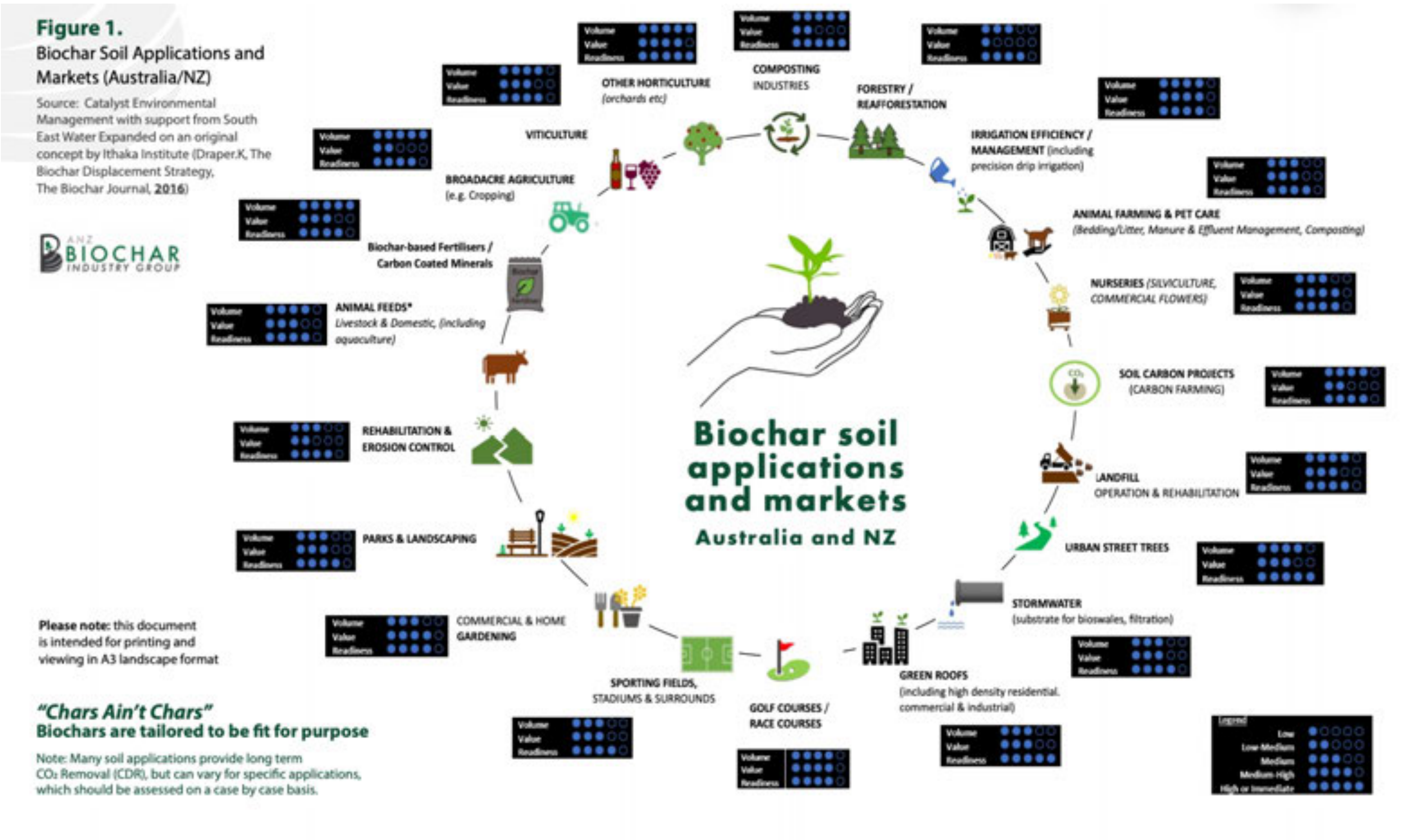
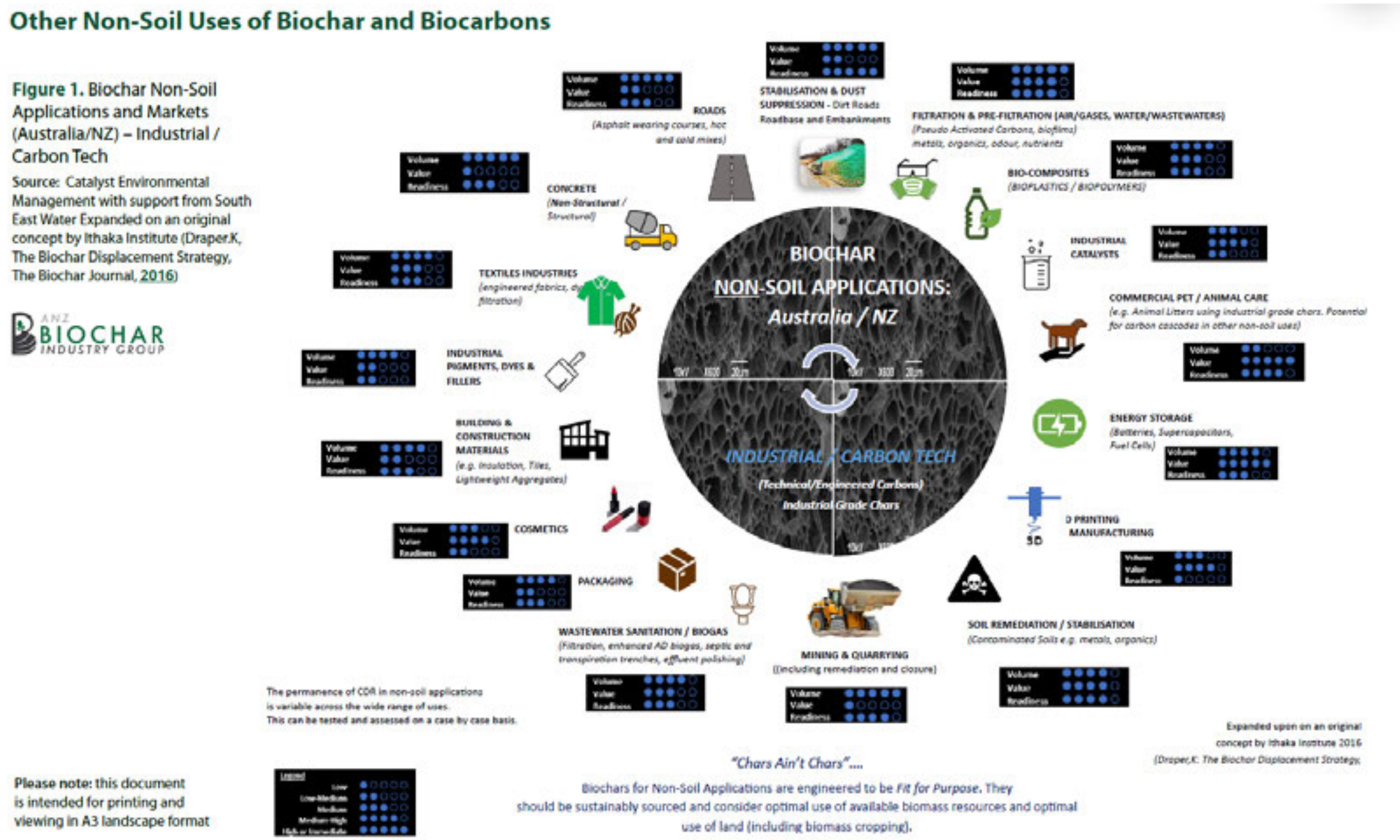


Figure 8: Industrial / Non-Soil Applications for *Industrial-Grade* Biochars/Circular Carbons



8 July 2024

Denmark bets on biochar for sustainable agriculture

Biochar in the spotlight: the Danish plan to cut agricultural emissions includes a huge EUR 1.35 billion investment. Chiaramonti (PoliTo): "This solution embraces economic competitiveness and will guarantee multiple benefits"

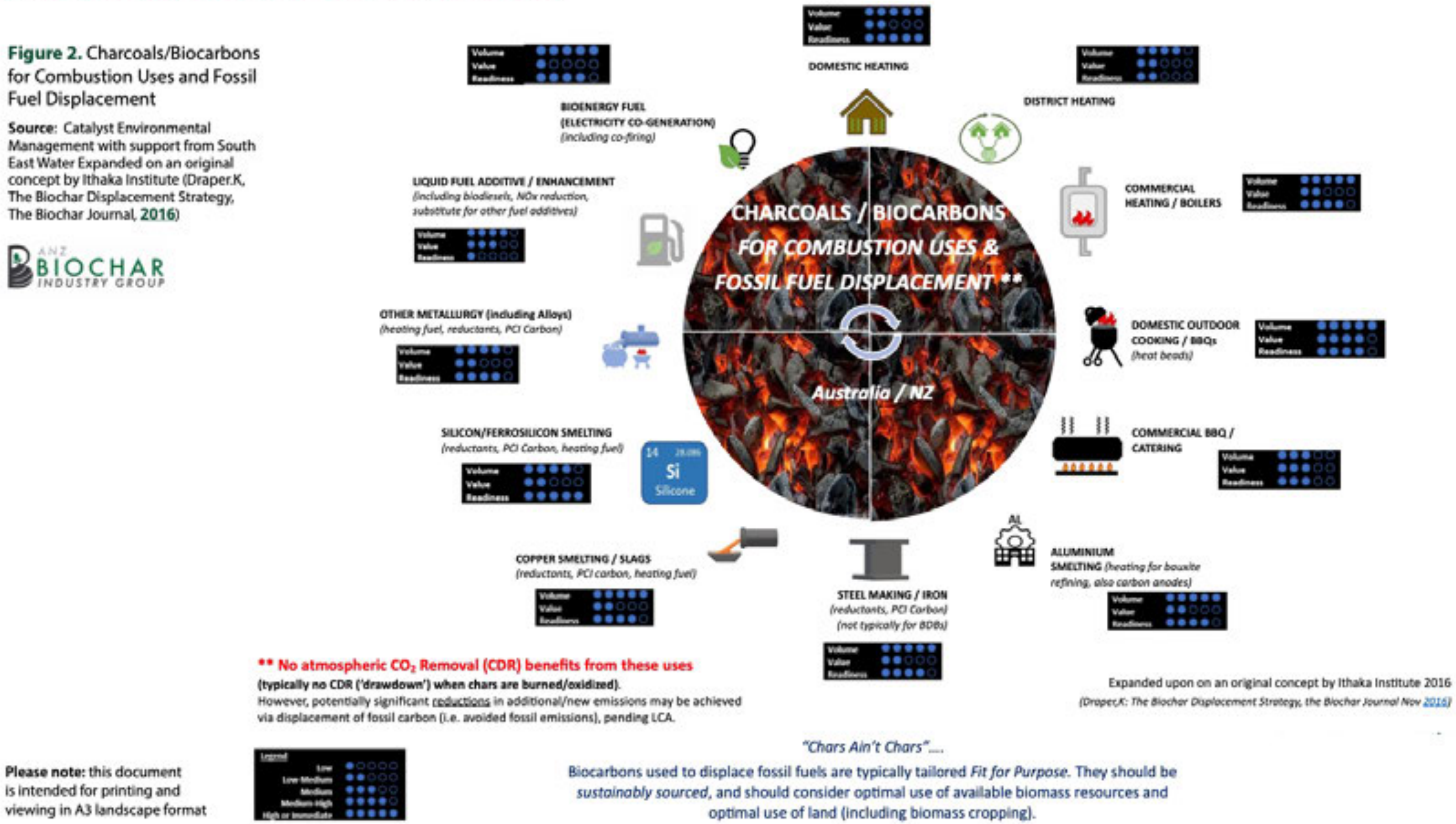
Denmark Publishes New Pyrolysis Strategy, Accelerating Biochar Adoption

by Sasha Ranevska · October 15, 2024 · 2 minute read

What are Biocarbons and other similar chars?

Biocarbons and other similar chars are also made from plant-based biomass (from plants in the current natural carbon cycle), however differ from 'biochar' via their end use **not** providing durable storage of the carbon in the long term (i.e. no long term sequestration >100 years). In these cases the carbon that had been captured by the plant material during its life and *temporarily* converted into solid char is **re-released back into the atmosphere**. As such, biocarbons and related chars are typically used for **combustive or oxidative purposes** such as **fuels and reductants.** These are illustrated in **Figure 9**.

Figure 9: Combustive and Oxidative Use for Circular Carbons (e.g. Biocarbons) These displace fossil fuels to reduce emissions but do not provide any significant durable carbon removal benefit (no CDR)



(ii) Circular Carbon via Fossil-based Carbons:

Pyrolysis technologies can also be used to process and 'recycle' **other** problematic carbon-based wastes including fossil-carbon-based materials into valuable solid carbon for **industrial chars** and valuable syngas co-products. For example, **end of life plastics**, **synthetic textiles**, **packaging**, **treated & engineered timbers, contaminated organics (PFAS, microplastics etc.) including from biosecurity events**), **C&D waste timbers and organic residues diverted from landfill,** among many more. These chars are **not called *bio*chars** as they are not biogenic (current carbon cycle) and do not provide CDR critical for Net Zero.

However, they do help to reduce, displace or avoid the need for new additional fossil-based carbon, contributing to **emissions reduction (ER)** urgently required for climate action. These circular fossil carbons could be considered for appropriate industrial grade applications (e.g. circular carbon black).

Emerging technologies can also process these fossil-based wastes as ***co-feeds*** with plant-based biomass (i.e. biogenic and fossil-based feeds combined).

When processing *plastics*, relatively low temperatures cause plastics to change state, with liquid and gas products commonly dominating yields, and lower solid char yield.

Figure 10: Fossil-based resources for circular carbon to reduce/avoid new emissions

Carbon Stewardship and Relevance to Circular Economy

The Ellen MacArthur Foundation, identifies 3 key principles for the circular economy, all driven by design:

1. Eliminate waste and pollution
2. Circulate products and materials (at their highest value)
3. Regenerate nature

'Traditional' product stewardship is currently overly recycling-focused. **Regenerative production** is an approach to managing agroecosystems that provide food and materials – be it through agriculture, aquaculture, or forestry – in ways that create positive outcomes for nature. These outcomes include, but are not limited to, healthy and stable soils, improved local biodiversity, improved air and water quality, and higher levels of carbon sequestration.[2]

Biochar is highly relevant to the circular economy, aligning with all three key principles:

- **Eliminate Waste and Pollution:** Biochar is produced by converting organic waste (e.g., agricultural and forestry residues) that would otherwise be burned or landfilled. This process not only reduces waste but also mitigates pollution by capturing harmful pollutants like PFAS and excess carbon.
- **Circulate Products and Materials:** Biochar provides long-term value across diverse sectors, including agriculture (improving soil health), construction (strengthening materials like concrete), and water treatment (as a filter medium). After serving its purpose, biochar remains beneficial as a soil amendment, ensuring it is circulated effectively through multiple life cycles.
- **Regenerate Nature:** By enhancing soil structure, water retention, and nutrient availability (Joseph et al 2021), biochar supports land repair, restoration and regeneration, particularly in degraded areas. Its ability to sequester carbon for centuries further aids in regenerating ecosystems by drawing down atmospheric CO_2 and locking it into soils, thus supporting nature's cycles of renewal.

The **Circular Economy with Carbon Stewardship** is an approach that integrates circular economy principles - such as eliminating waste, circulating resources, and regenerating ecosystems - while actively managing and reducing carbon emissions. By incorporating carbon stewardship, the circular economy prioritises not only the reuse and recycling of materials but also the removal and sequestration of carbon through

[2] Source: Ellen Macarthur Foundation

technologies like biochar. This enables businesses and industries to operate sustainably while addressing climate change.

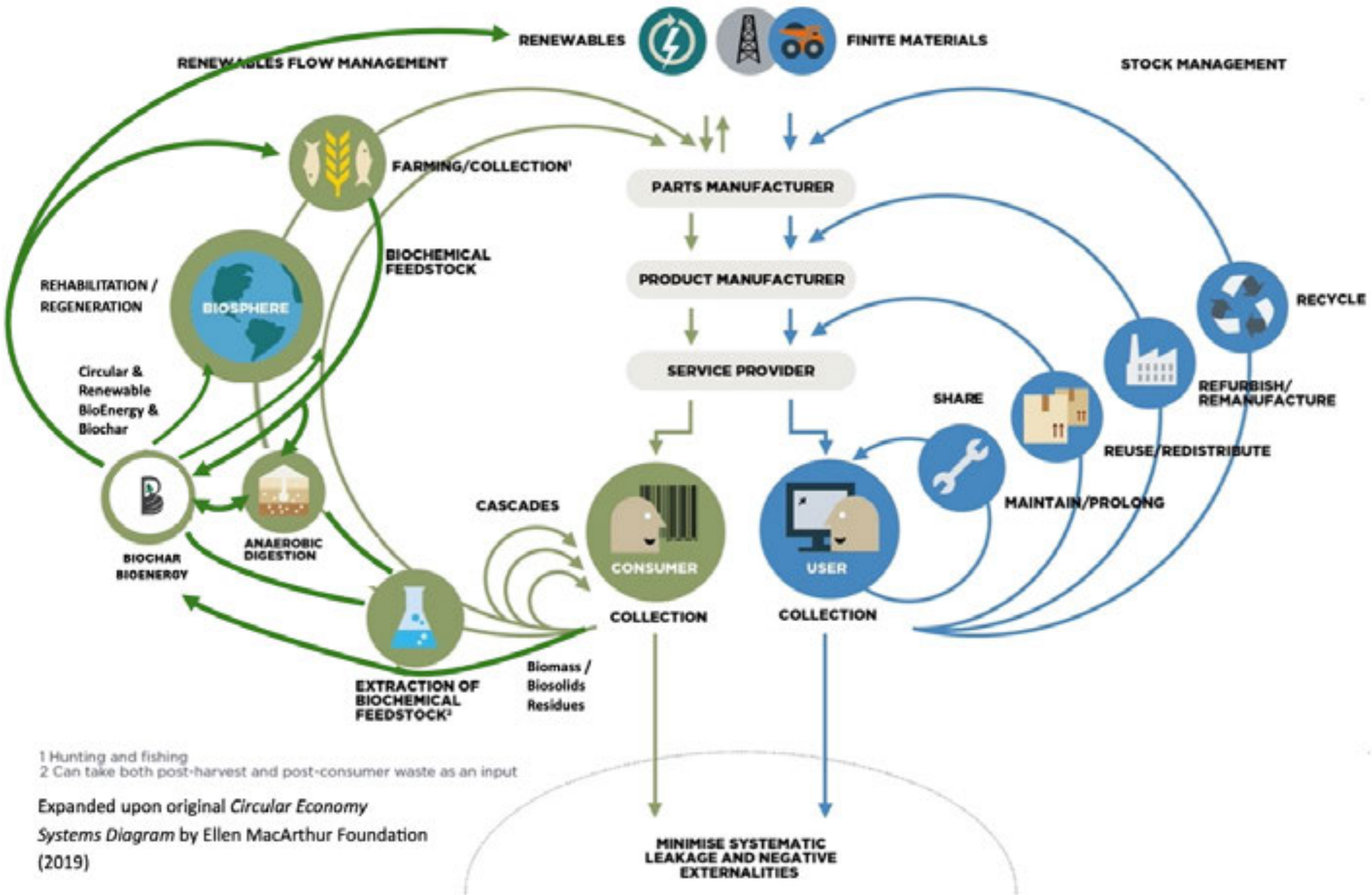
This model helps transition away from the traditional linear economy, where resources are extracted, used, and discarded. Instead, a circular economy creates closed loops of resource use, keeping materials in continuous circulation at their highest value. **Carbon stewardship** ensures that carbon emissions are minimised throughout these processes and that any unavoidable emissions are actively removed from the atmosphere. This synergy supports **net-zero** and **climate-positive** goals.

The Ellen MacArthur Foundation's circular economy butterfly diagram could be expanded upon to include carbon stewardship by adding explicit loops for **circular and renewable bioenergy and biochar** (**Figure 12**). These loops highlight the role of processes like biochar production, carbon-negative technologies, and renewable energy generation in actively removing and storing carbon, thus enhancing the overall climate-positive impact of the circular economy.

Further, circular economy with carbon stewardship ties into broader sustainability efforts, such as the UN Sustainable Development Goals (SDGs) (see Figure 11), by addressing environmental, economic, and social challenges. By promoting regenerative practices, biodiversity conservation, and enhanced food and water security, this approach not only mitigates climate impacts but also builds resilient, future-ready systems that can sustain human and ecological well-being.

Figure 11: Biochar bioenergy can positively contribute to over ¾ of the UN SDG's

Figure 12: Towards a Circular Economy and Net Zero Through Stewardship of Carbon from Biomass



Circular Economy Success Stories and Measures of Success

By embracing biochar and related technologies and integrating them into economic and environmental strategies, we can make significant strides toward a sustainable, resilient, and circular economy. Biochar not only addresses waste and pollution but also circulates materials at their highest value and adds value to materials (upcycles), and can help to regenerate nature (particularly degraded soils), concurrent with providing important climate action via ER and CDR, making it a powerful tool in the transition to a more sustainable future. These aspects are outlined further below.

Additionally, appended to this submission are the following important supporting documents which provide further detailed information (**including case studies**) **of commercial success stories** for biochar used in both soil and non-soil/industrial applications, illustrating the potential for the industry to contribute to circular economy:

Appendix 1: ANZBIG 2024, Australian Biochar Industry 2030 Roadmap (V2.0)

Appendix 2: Martin R (GlobalPSC) & Bagnall C(SEATA) 2024, *"Towards a Circular Economy and Net Zero Through Carbon Stewardship"*, presentation to the 2nd Annual International Conference on *Circular Economy for Climate and the Environment* (CECE, Sydney 2024).

Appendix 3: ANZBIG 2024 presentation, *"Australian Biochar Industry 2030 Roadmap"* - A multi-billion dollar industry removing carbon, increasing revenue and increasing agricultural GVP.

Appendix 4: WSAA 2024, Extract (biochar technical paper) from WSAA submission to CEMAG, "*Help us Help You – Australian water Sector opportunities and barriers to Circular Economy*"

Appendix5: WSAA 2023, Information Factsheet: '*Biochar 2 Batteries' Project*

Appendix 6: IBI 2024, *2023 Global Biochar Market Report*

Appendix 7: Taylor P and Joseph S 2024, *A Farmer's Guide to the Production, use and application of biochar*", via ANZBIG, **includes updated**

case studies. **Note**: *Provided **commercial-in-confidence,** not for wider distribution (commercial product).*

Appendix 8: Robb S and Joseph S 2020, Biochar User's Report: *"A report on the value of Biochar and Wood Vinegar"*, presenting economic case studies and **Net User Benefits** ($$ per tonne of biochar).

Appendix 9: ANZBIG 2024, presentation: *"Circular and Regenerative Bioenergy: Pathways for CO2 Removal and Renewable Energy for Net Zero via the Australian Biochar Industry 2030 Roadmap"*, Australian Bioeconomy Conference 2024, Australian Industrial Ecology Network.

Eliminate Waste and Pollution

Transformation of Organic Waste into Valuable Resources and Products

- **Utilising and *Upcycling* Biomass Waste:** Biochar production converts organic waste materials—such as agricultural residues, forestry by-products, municipal green waste, and even problematic wastes like biosolids—into valuable products. This process diverts waste from landfills and open burning, reducing methane emissions and other pollutants.
- **Syngas Utilisation and Energy Circularity:** The pyrolysis process produces syngas, a renewable energy source that can be used for heating, electricity generation, or converted into biofuels like hydrogen and methanol. Using syngas reduces dependence on fossil fuels, promoting a circular energy economy where energy is generated from renewable resources and waste materials.
- **Pollution Mitigation:** Pyrolysis, the process of creating biochar, thermally decomposes organic materials in the absence of oxygen, effectively destroying harmful pollutants like persistent organic pollutants (POPs) and pathogens. This results in a cleaner environment and reduces health risks associated with waste pollution.
- **Treatment of Emerging Organic Contaminants: Some organic waste streams** (such as municipal biosolids, which is a critical source of non-renewable phosphorus for agriculture) can contain organic contaminants like PFAS and microplastics that can be safely processed and thermally deconstructed into biochar, neutralising otherwise harmful substances and preventing soil and water contamination, and facilitating circularity for materials that may otherwise be ultimately destined for landfill.

Opportunity - Better Management of Biomass/Biowastes:

There is a significant opportunity for better management of biomass and biowastes currently going to waste. Globally, **biochar's carbon dioxide removal (CDR) potential is estimated to be up to 6.6 gigatonnes of CO_2e per year**, with up to 1.8 gigatonnes per year achievable at a cost below USD $100 per tonne of CO_2e (IPCC 2022).

In Australia, **at least 50 million tonnes of biomass every year is either burned, sent to landfills or otherwise under-utilised** (ANZBIG 2022). For example a detailed study by scientists at CSIRO (Crawford et al 2016) estimated that up to 80-110 million tonnes per year could be sustainably available for bioenergy production. This wasted biomass could be redirected to produce biochar, which can enhance food production, improve soil fertility, and contribute to climate mitigation efforts by sequestering carbon in stable forms whilst concurrently providing syngas for bioenergy.

In New South Wales alone, over 22 million tonnes of biomass residues are available each year (NSWDPI 2021). These could be harnessed to support sustainable agricultural practices, improve food security, and build a circular bioeconomy.

By turning biomass waste into biochar, Australia could significantly reduce emissions while creating valuable products for agriculture and energy. Biochar production not only reduces waste and pollution but also promotes better land use, enabling greater resilience and sustainability in food systems.

In 2023, Biochar CDR delivered over 90% of the CO2 removal in the global voluntary CDR market, yet only received around 12% of the funding for all CDR mechanisms. Accordingly, biochar provides significant 'bang for buck' worthy of increased support.

Biochar can help to **'upcycle'** wasted or degraded materials into a higher value form for use throughout the economy in both soil and industrial/non-soil applications, helping to circulate them at their highest value.

- **Soil Amendment for Agriculture:** Biochar improves soil fertility by enhancing nutrient retention, water holding capacity, and microbial activity. This leads to higher crop yields and reduces the need for synthetic fertilisers, keeping the biochar functional in soils for centuries.

- **Upcycling Biosolids to ensure continued circularity of vital non-renewable Phosphorous (P) resources back into agricultural soils** – as noted in the previous section biosolids are increasingly constrained by emerging contaminants. Thermal treatment by pyrolysis and gasification has been demonstrated (both here and internationally) to appropriately deconstruct these to facilitate their ongoing return to help regenerate agricultural soils.
- **Urban Soil Amendments can provide both climate adaptation *and* mitigation** – biochar is an excellent substrate for green roofs, street trees and sporting fields due to its high water holding capacity. These applications can help retain stormwater runoff for climate adaptation in the battle against increasing rainfall intensities and flooding, whilst concurrently providing CDR to aid efforts to maintain climate change globally to within 1.5 degrees.
- **Industrial Applications:** Biochar can replace non-renewable and carbon-intensive materials in various industries, ensuring materials remain in use at their highest value.

Examples:

- **Construction Materials:**
  - **Green Concrete:** Incorporating biochar into concrete reduces its carbon footprint and can improve strength and durability. Biochar-modified concrete keeps carbon locked within the building materials.
  - **Asphalt Enhancement:** Adding biochar to asphalt improves its performance and lifespan, reducing maintenance and material waste.
- **Water Filtration:** Biochar's porous structure makes it an excellent filter for removing impurities from water. After its life as a filter, biochar can be regenerated or used for various soil and non-soil applications, extending its utility.
- **Bioplastics and Composites:** Biochar serves as a sustainable filler in bioplastics, enhancing material properties while reducing reliance on fossil fuels.

Opportunity - Circular Use in Roads, Stabilisation & Construction Materials:

Example: Winner of the 2023-24 Biochar Industry Award for industrial uses:

HIWAY GROUP is the largest specialist in sustainable pavement and road recycling technology in Australia. Their specialised cold in-situ pavement solution adopts new and innovative binder technologies, supplied in partnership with C-Twelve, delivering an improvement in material performance and lifespan while sequestering carbon within the infrastructure, reducing carbon emissions, saving in construction time and minimising the use of new virgin materials by up to 95%.

Regenerate Nature

Restoring Ecosystems and Enhancing Biodiversity

- **Carbon Sequestration:** Biochar locks carbon into a stable form that can remain in soils for hundreds to thousands of years, effectively removing CO_2 from the atmosphere and mitigating climate change.
- **Soil Restoration:** Applying biochar to degraded or contaminated soils enhances fertility, improves structure, and promotes microbial life, leading to healthier plant growth and restored ecosystems.

Examples:

- **Mine Rehabilitation:**
  - **Soil Improvement:** Biochar application on post-mining lands improves soil quality, enabling vegetation growth and ecosystem restoration.
- **Agricultural Benefits:**
  - **Increased Crop Yields:** Studies have shown that biochar can increase agricultural production by 10-42%, contributing to food security.
  - **Water Conservation:** Biochar's ability to retain water reduces irrigation needs, supporting agriculture in arid regions and enhancing drought resilience.

- **Biodiversity Enhancement:** By improving soil health, biochar supports a wider variety of plant species, which in turn supports diverse insect and animal life, fostering robust ecosystems. The New South Wales Department of Primary Industries has demonstrated how biomass can be grown for biochar by growing native biomass crops on degraded soils, promoting ecological recovery.
- **Climate Change Mitigation:**
  - **Carbon Credits and ACCUs:** Biochar projects could generate Australian Carbon Credit Units (ACCUs), providing financial incentives for carbon sequestration and supporting national and global climate goals.
  - **Contribution to Net Zero Targets:** By sequestering carbon and reducing emissions from waste decomposition, biochar helps organisations and governments meet net zero emissions targets.

Opportunity - Soil Applications for Biochar:

A global review of over two decades of biochar research, conducted by **Joseph and Cowie et al.** (**2021**), highlights several key benefits of biochar in soil applications. Studies show biochar can increase agricultural production by **10-42%**, depending on the application rate (**Ye et al., 2019**). Additionally, it significantly enhances soil phosphorus availability by a factor of **4.6x**, promoting better crop nutrition.

Moreover, biochar reduces **non-CO_2 greenhouse gas emissions** from soil by **12-50%**, including a 5**0% reduction in N_2O emissions** (**Cayuela et al., 2014**). It also boosts the soil's **water holding capacity**, improving drought resilience and contributing to long-term soil health (**Bryant 2015; Joseph et al., 2021**). These findings underline biochar's potential to improve agricultural efficiency while combating climate change.

Figure 12: Example retail products from Australian commercial producers

Priority Opportunities to Progress the Circular Economy

Biochar's Potential

ANZBIG (2024) estimated that conversion of the more than 50Mtpa of commercially accessible biowaste residues currently being burned, landfilled or otherwise under-utilised in Australia **each year** into biochar bioenergy has the **potential to reduce Australia's net carbon emissions by 10-15% and provide up to 20,000 permanent jobs** (particularly in regional and rural areas), whilst improving soil health and agricultural productivity and returning degraded lands to higher value.

ANZBIG (2024) indicatively estimated that the **potential economic benefit of converting Australia's >50Mtpa of biowastes into biochar bioenergy** to assist Australian Agriculture could result in a total of over **$12.5 billion worth of benefits *every year***:

- **$5-7.5B/yr** worth of biochar as a physical commodity
- **$3B/yr** worth of biochar CO_2 removal carbon credits (B-CDR)
- **$2B/yr** worth of agricultural productivity gains (e.g. yield)
- **$16.5M/yr** worth of renewable energy
- **$90M/yr** worth of soil carbon growth (plus significant reductions in GHG released from agricultural soils through use of biochar, ranging 12-50%)
- **$32M/yr** worth of water savings (through a conservative 0.5% increase in soil carbon across 10% of agricultural lands).

A summary of opportunities for displacement of (solid) fossil carbon products throughout the economy is provided further below. Figures illustrating example opportunities for feedstocks and market for soil and non-soil applications of biochar and biocarbons were provided earlier in **Figures 6-9**. Examples of existing commercial applications are outlined in the presentations contained in **Appendices 2, 3** and **9.**

Displacing fossil carbon throughout the economy involves replacing fossil-based materials and fuels with biochar and 'biocarbon'[3] derived from biomass. Biochar can be

[3] The term 'biocarbon' is used instead of 'biochar' if there is no durable carbon dioxide removal benefit. It is noted the uses of biocarbon can result in the displacement of fossil fuels which reduce new emissions and contribute to emissions reduction targets.

used in a wide range of industries to substitute for materials like **carbon black**, **metallurgical coal**, **peat**, **synthetic fertilizers**, and **graphite**. This displacement reduces the need for fossil carbon, helping decarbonise supply chains while maintaining or improving technical performance, such as enhancing material strength, filtration, and nutrient retention.

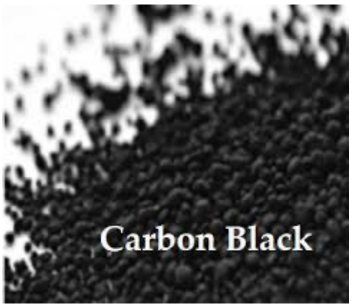
In hard-to-abate industries like **metallurgy**, biochar acts as a renewable reductant, displacing **metallurgical coal** while contributing to both **emissions reduction** and **carbon dioxide removal**. Biochar's use extends to the **horticulture** industry, where it replaces fossil-derived **peat** and improves soil health, supporting circular economy goals. In **agriculture**, biochar substitutes **synthetic fertilizers**, reducing reliance on natural gas-derived products, while enhancing soil water retention and nutrient efficiency.

In the **manufacturing** and **energy sectors**, biochar displaces **plastics**, **graphite**, and **fossil-derived activated carbon**, promoting sustainability across supply chains. For example, **biochar** can be used in **battery anodes** or in **biocomposites**, contributing to the reduction of fossil-based materials in industrial applications. This cross-sector use of biochar supports decarbonisation efforts while providing additional benefits in technical performance, circularity, and environmental sustainability.

Example opportunities for solid circular carbons (e.g. biochar) to displace fossil carbon products throughout the economy and its supply chains:

- *Displacement of **Carbon Black** (fossil carbon derived)*
- *Displacement of **Activated Carbon** (lignite/coal)*
- *Displacement of **Coal** (e.g. metallurgical reductants – "**biocarbons**")*
- *Displacement of **Peat** (horticulture/nurseries/agriculture)*
- *Displacement / Reduction of **Synthetic Fertilizers** (derived from natural gas)*
- *Displacement of **mined Graphite** (fossil-based) (used in battery anodes etc.)*
- *Displacement of **Recarburiser** (fossil-based) (used in foundries)*
- *Displacement of **Plastics/Oil** (e.g. fillers, biocomposites)*

In addition to the above, biochar can also be used to improve the technical and environmental performance of materials in hard to abate sectors such as **concrete**. Further, liquid and gaseous circular carbons similarly provide significant opportunities to displace fossil carbons throughout the economy (e.g. energy and circular fuels), as illustrated earlier in this submission in **Figure 3**.

Potential Additional Benefits from Supporting the Circular Economy with Carbon Stewardship:

- **Renewable Energy Production**
    - **Syngas Utilisation for Energy & Circular Fuels:** The pyrolysis process produces syngas, a renewable energy source that can be used for heating, electricity generation, or converted into biofuels like hydrogen and methanol (refer Figures 2 and 3).
    - **Energy Circularity:** Utilising syngas reduces dependence on fossil fuels, promoting a circular energy economy where energy is generated from renewable resources and waste materials.
- **Climate Change Mitigation**
    - **Carbon Credits and ACCUs:** Biochar projects could generate Australian Carbon Credit Units (ACCUs), providing financial incentives for carbon sequestration and supporting national and global climate goals.
    - **Contribution to Net Zero Targets:** By sequestering carbon and reducing emissions from waste decomposition, biochar helps organisations and Government meet net zero emissions targets.
    - **Reduction in Scope 3 Emissions (as well as 1 and 2) –** contributing to decarbonisation throughout supply chains across many industries and areas of the economy, including **hard to abate** industries such as concrete, steel and aviation (among others).
- **Economic and Community Benefits**
    - **Job Creation:** Developing the biochar industry would create jobs in rural and regional areas, supporting economic diversification and resilience in communities transitioning from traditional industries (e.g. mining).

  - **Investment Opportunities:** Biochar presents attractive investment prospects in sustainable technologies, renewable energy, and environmental services.
- **Waste Reduction in Supply Chains**
  - **Circular Agriculture:** Biochar enables a closed-loop system where agricultural waste is converted into a resource that enhances future crops, reducing the need for external inputs.
  - **Industrial Symbiosis:** Industries can exchange waste materials for biochar production, promoting symbiotic relationships that reduce overall waste and resource consumption.

Figure 14: Extracts from the *2023 Biochar Global Market Report* regarding opportunities for biochar and syngas (source: IBI 2024)

Adding Value to Raw Biochar

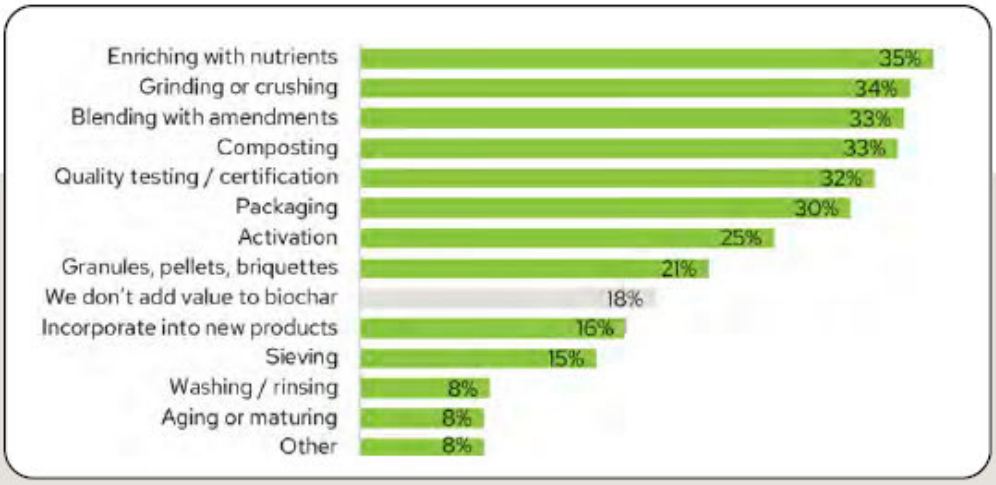


Figure 19. Biochar producer responses when asked "What post-production processes do you use to add value to the biochar you produce? (Please select all that apply)".

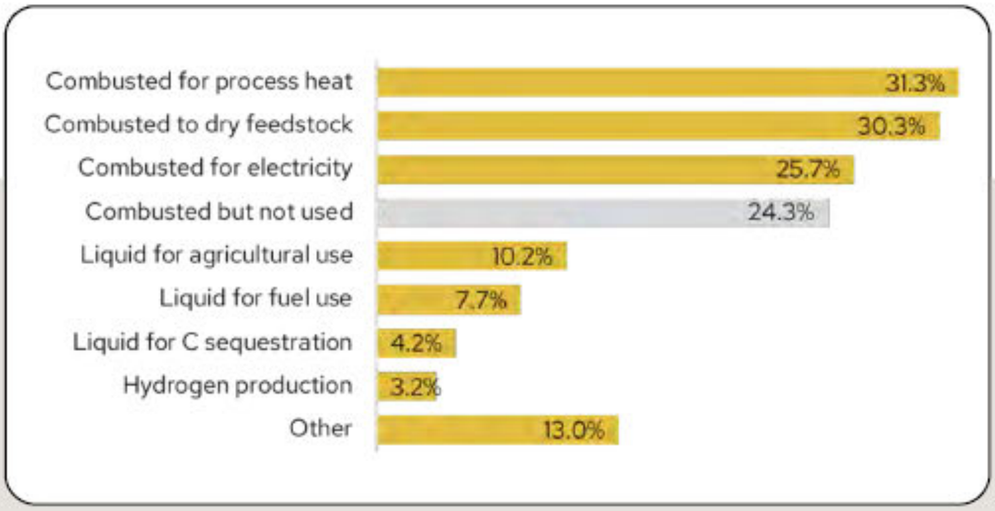


Figure 20. Pyrolysis gas end-use among producers when asked "How do you utilize pyrolysis gas in your biochar production process? (Please select all that apply)".

AGRICULTURAL USERS

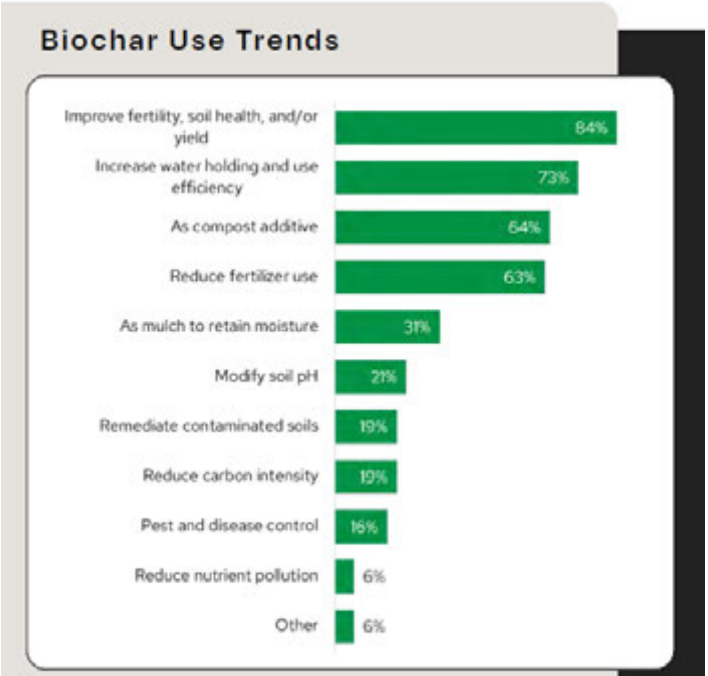


Figure 27. Reasons for agricultural producers to use biochar when asked "How are you currently using biochar in your agricultural practices? (Please select all that apply)".

Biochar Use Trends

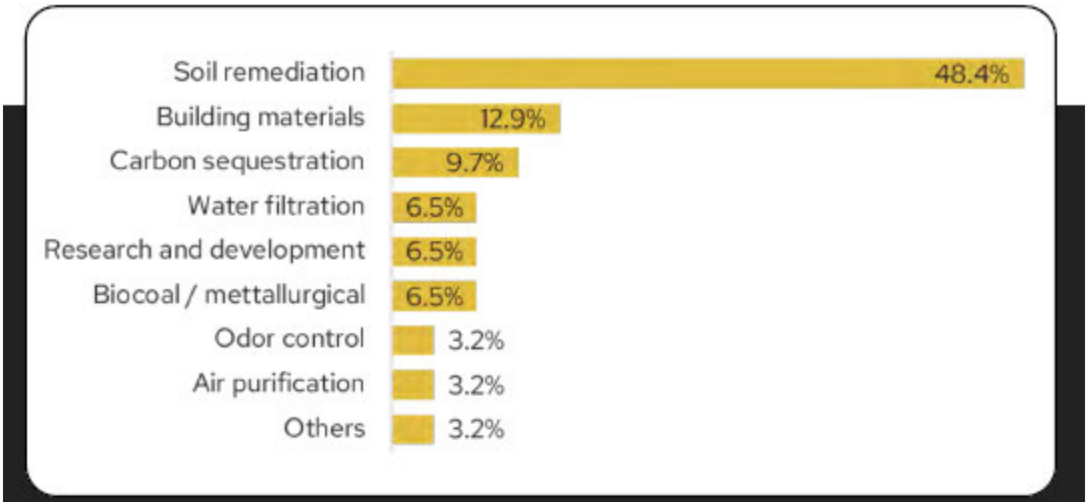


Figure 28. End-uses among non-agricultural biochar users when asked "What is your primary use of biochar? (Please select one)".

Figure 15: Example opportunities in the water industry (source: WSAA)

WATER OPPORTUNITIES SUMMARY

HELP US HELP YOU

AUSTRALIAN WATER SECTOR OPPORTUNITIES AND BARRIERS TO CIRCULAR ECONOMY

1. Biochar: Carbon sequestration from wastewater treatme

This is an innovative way to use the biosolids which are extracted at wastewater treatment plants all around the country. These biosolids can be thermally treated to produce a product (Biochar) that can capture and store carbon, destroy potential contaminants, and is a valuable soil improver.

Biochar is not the only option for how our industry could beneficially recycle organics – a range of options are available. However, as it is an opportunity that offers multiple benefits, and for which there is a well-documented roadmap, it is a good candidate to try and accelerate progress through CE MAG collaboration.

Biochar could add up to $700 million [3] to the Australian economy and make a substantial contribution to national decarbonisation goals. There are clear, concrete steps for different governments to help optimise the use of biosolids for biochar:

- Commonwealth – support creation of an ACCU method for biochar. The IPCC already lists it as an emissions reduction and CO2 removal pathway. This would open up valuable offset markets.
- Commonwealth – provide funding support for initial adoption of technologies to convert biosolids to biochar, and support market development for end users of biochar products.
- State/territory – address a regulatory barrier by decoupling the heat treatment methods for biochar (pyrolysis and gasification) from incineration, in the waste hierarchy. Pyrolysis and gasification, also known as carbonisation, provide uplift by turning biomass into stable carbon, rather than releasing it to the atmosphere, and produce renewable energy as a co-product. Incineration is also a mature technology with its own pros and cons, but the three are different and should not be grouped together.
- State/territory – change the classification of biosolids, and biochar derived from biosolids, as a waste, which typically attracts a waste levy and is challenging to move across borders. Instead classify them as a product or resource, to remove constraints and improve their marketability.
- The industry is working on understanding the geographic scales at which biochar from biosolids is commercially feasible, versus where funding support might be needed initially – we would welcome working with the CE MAG and other relevant organisations on this.

[3] Industry estimate based on potential market value of biosolids to higher value biochar

3

Feasibility for Uptake and Measures of Performance

The ANZ Biochar Industry Group (ANZBIG) *Australian Biochar Industry 2030 Roadmap* (Roadmap) outlines comprehensive research on biochar applications and markets, highlighting the potential for biochar in rural and urban soil applications, non-soil industrial uses, and oxidative and combustive uses ('biocarbons'). The Roadmap emphasises biochar's critical role in carbon sequestration, soil improvement, and its ability to replace fossil carbon in various industries. **Each of the ten (10) key initiatives and supporting actions within the roadmap include performance measures** via specific **KPIs** *and* (additionally) alignments with **measurable UN SDGs**. Refer **Appendix 1** to this submission for details.

In addition to the actions and measures to accelerate uptake identified within the Roadmap, the following also have been developed to facilitate rapid uptake for the industry:

- **Code of Practice for the Sustainable Production and Use of Biochar** (ANZBIG 2021), currently under review (V2.0 due shortly)
- **Farmer's Guide to the Production, Use and Application of Biochar** (Joseph and Taylor 2024, via ANZBIG)
- **Proposed ACCU Method for Biochar CO2 Removal** (B-CDR) credits (ANZBIG / Cross-industry Working Group 2024)
- **Proposed Australian Standard** for Biochar, Biocarbons and Associated Product Quality and Grading (Accelerated Pathway) – November 2024 (scoping brief for its development just released for public consultation).
- Proposed ***Certification Scheme*** for Biochar Production and Quality (under development by ANZBIG)

An infographic illustrating 'fit-for-purpose' biochar quality grades under the ANZBIG Code of Practice is provided in **Figure 16**. The wide range and scale of Australian technologies available for sustainable production of biochar and biocarbons is illustrated in **Figure 17**. ANZBIG has established strong collaborative working relationships (including MOUs) with multiple industry groups and associations, just for example including WSAA, AORA, GlobalPSC, Farmers for Climate Action, and the cross-industry working group that recently collaboratively proposed an ACCU method for biochar carbon removal, among many others.

Accordingly, the ANZ Biochar Industry stands "shove-ready" for rapid scale up, with a Roadmap to facilitate such with wide cross-industry support. All that is required is government support to implement it. We welcome further discussions to this end.

For **rural and urban soil applications** (Figure 7), biochar improves soil fertility, water retention, and nutrient efficiency. Examples include its use in agriculture to enhance crop yields and in urban green spaces to support sustainable landscaping practices. Biochar applications in soil help sequester carbon, contributing to climate resilience in both rural and urban settings.

In **non-soil and industrial applications** (Figure 8), biochar can be used as a renewable replacement for materials like activated carbon, carbon black, and synthetic additives in construction materials and filtration systems. Biochar has been applied in bioplastics and as a component in concrete, improving material strength and sustainability. Additionally, for **oxidative and combustive uses** (Figure 9), biochar serves as a renewable reductant in metallurgical processes and can replace fossil fuels in high-temperature applications, making it highly valuable for decarbonising energy-intensive industries.

Figure 16: Facilitating Fit-for-Purpose Products – Biochar Quality Grading and Classification

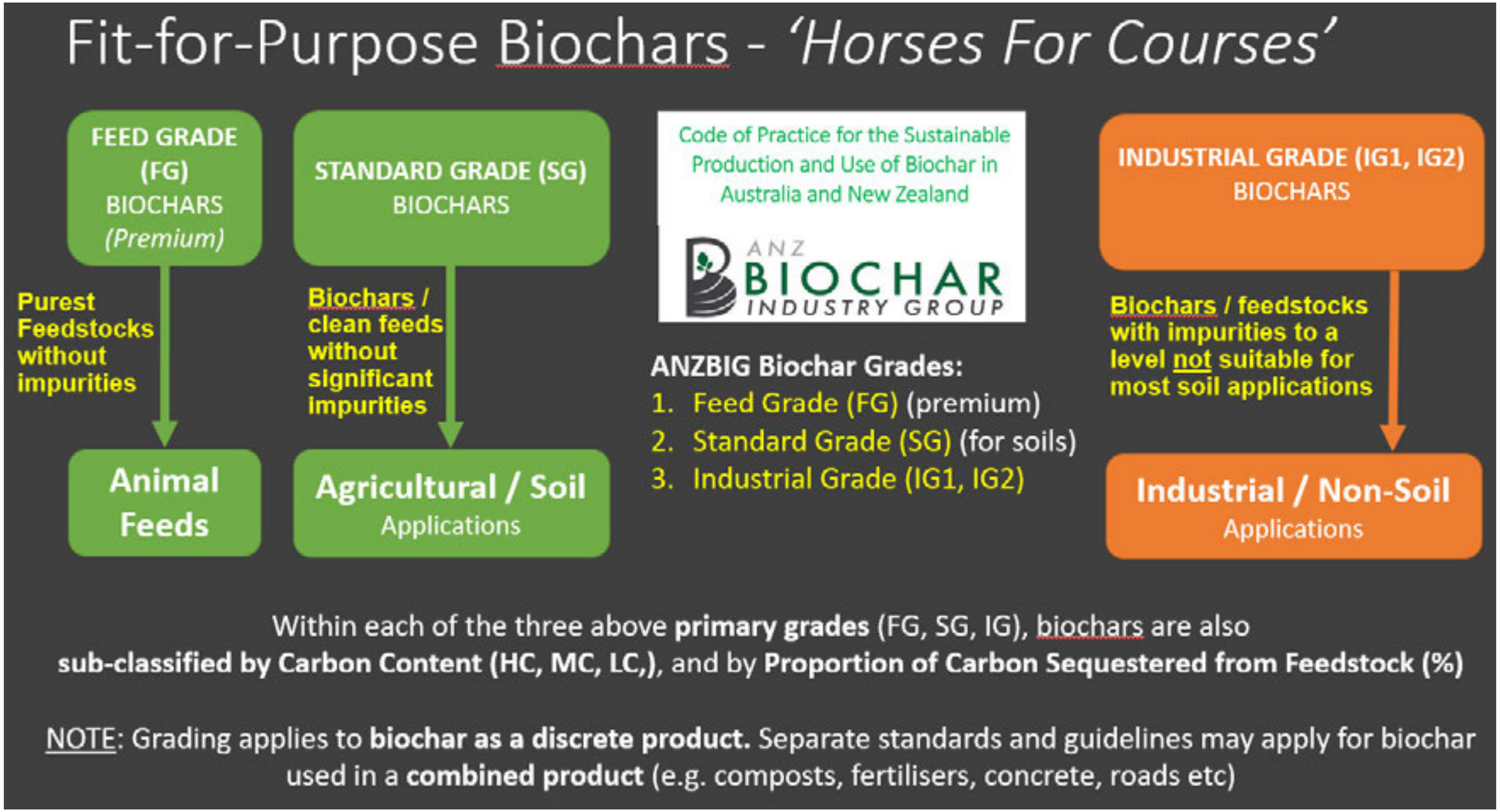


Figure 17: Australian Biochar Technologies – a wide range of types, scales and outputs ("horses for courses")

Important Links with Indigenous Knowledge & Land Management

Biochar has been made by First Nations people around the world for thousands of years, including right here in Australia by our indigenous people - the oldest continuing culture on the planet. Biochar was made in *earth ovens* (Figure 18) similar to those used by many first nations peoples throughout the Pacific (such as the Māori 'Hāngi'), enriching soils in the process (refer here and details in *Terra Preta Australis* (Downie & Van Zwieten et al 2010)). **The modern biochar industry presents a significant opportunity for continued and important indigenous involvement.**

Figure 18: *Biochar has been made by First Nations people around the world for thousands of years, including right here in Australia by our indigenous people - the oldest continuing culture on the planet.*

Biochar production from excess biomass material can play an important support role in reducing the risk of high-intensity wildfires, which have devastating environmental, social and economic impacts. During the **2019-2020 Australian bushfires**, 5.5 million hectares were burned, causing significant losses to biodiversity, infrastructure, and carbon stocks, and emitting **830 million tonnes** of CO_2e.[4]

By using forest residues and other biomass to produce biochar, excess fuel loads that drive intense wildfires are reduced. This approach aligns with **Indigenous fire management practices**, which focus on controlled burns to manage fuel loads and protect landscapes. Integrating biochar projects into these traditional methods can enhance the regenerative potential of ecosystems, protecting biodiversity, carbon stocks, and cultural heritage from wildfire destruction.

Indigenous land management has long used controlled burns as a means of preventing large-scale fires. Biochar production could complement these practices by sequestering carbon and enhancing soil health in fire-affected areas, further regenerating damaged ecosystems.

[4] Australian Government Department of Industry, Science, Energy and Resources, *Estimating greenhouse gas emissions from bushfires in Australia's temperate forests: focus on 2019-20*, April 2020.

Potential benefits of biochar projects include:

- **Carbon sequestration:** Biochar locks carbon into soils, reducing atmospheric CO_2 and enhancing long-term ecosystem resilience.
- **Ecosystem regeneration:** Biochar improves soil health, helping ecosystems recover after fires by boosting water retention and fertility.
- **Cultural and Environmental Preservation:** Combining biochar with Indigenous knowledge can protect cultural heritage and restore fire-sensitive environments.

By promoting biochar initiatives in fire-prone regions, we can not only reduce wildfire intensity but also regenerate ecosystems, protect biodiversity, and contribute to a circular, climate-positive economy.

Alignment with Multiple Government Policy Objectives

Australian Biochar Industry 2030 Roadmap

Carbon plays a central role in so many areas of our economy and in government policy objectives. The production and use of biochar can contribute positively toward multiple policy objectives concurrently, including (but not limited to) the following Commonwealth objectives listed below (**Figure 19**). State and Local government objectives are similarly assisted.

Supporting the biochar industry to contribute to these important areas can leverage government investment toward achieving the targeted outcomes. The ANZ Biochar Industry Group has developed the Australian Biochar Industry 2030 Roadmap to outline 10 key priority theme target areas with 10 supporting primary actions to accelerate the industry, Government support toward implementing the Roadmap is encouraged.

Figure 19: Biochar industry alignments with Multiple Government Policy Objectives

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2030 ROADMAP
PAGE 9

Alignment with Multiple Government Policy Objectives

Carbon plays a central role in so many areas of our economy and in government policy objectives. The production and use of biochar can contribute positively toward multiple policy objectives concurrently, including (but not limited to) the following Commonwealth objectives below. State and Local government objectives are similarly assisted. Supporting the biochar industry to contribute to these important areas can leverage government investment toward achieving the targeted outcomes.

Climate Change / Climate Resilience / Net Zero

- Net Zero Plan (Net Zero by 2050). Biochar can provide significant contributions toward all six sectoral plans to achieve net zero:
  - Agriculture and Land; Built Environment ; Electricity and Energy
  - Transport & Infrastructure ; Industry ; Resources.
- 43% Emissions Reduction by 2030 (Climate Change Act, 2022, Paris Agreement)
- National Climate Resilience and Adaptation Strategy 2021 – 2025
- Net Zero in Government Operations Strategy
  - Australian Public Service Net Zero Emissions by 2030
  - *Partnership in the (international) Net Zero Government Initiative*
- National Strategy for Disaster Resilience
- Australian Disaster Preparedness Framework / Sendai Framework
- Australian Carbon Credit Unit (ACCU) Scheme – a cross industry working group including ANZBIG has lodged an EOI for a new method for Biochar Carbon Dioxide Removal.
- Bid to Co-Host COP31 (2026) - Enhancement of action supporting COP31 with the Pacific
- National Science and Research Priorities

Circular Economy / Sustainability / Waste

- National Wate Policy (NWP) (2018) and NWP Action Plan (2019)
  - 50% reduction in organic waste to landfill by 2030 (Target 6)
  - Recover 80% of all waste by 2030 (Target 3)
  - Significantly increase the use of recycled content by governments and industry (Target 5)
- National Circular Economy Framework
- Circular Economy Ministerial Advisory Group (CEMAG) – Priority action areas:
  - Built Environment and Net Zero
  - Innovation and Skills
  - Food, Resources and Regions
  - Circular Design & Consumption of Products
- 2030 Agenda for Sustainable Development and the Sustainable Development Goals
- Australian Sustainability Reporting Standards – (draft) Disclosure of Climate Related Financial Information (EDSR1).
- Remade in Australia – circular carbon that concurrently also provides climate action.
  - Environmentally Sustainable Procurement Policy & Reporting Framework
- National Science and Research Priorities

Agriculture (Production / Climate Resilience)

- Delivering AG2030: Australian Agricultures vision for a $100 Billion Industry by 2030
  - Production (output/yield); Biosecurity; Land Stewardship
  - Water and infrastructure; Innovation & Research
  - Human Capital – rural and regional skills and employment
  - $100B in agricultural production by 2030
  - Halve Food Waste by 2030
  - 20% increase in water use efficiency for irrigated agriculture by 2030
  - Produce more from existing land - maintain Australia's total farmed land at 2018 levels
- National Soil Strategy (2023-2028) and National Soil Action Plan
- Carbon Farming Outreach Program
- Australian government commitments to the UN Convention to Combat Desertification (UNCCD)
- Climate Resilient Agricultural Development and Food Security Program
- National Science and Research Priorities

Water Efficiency / Drought Resilience

- National Water Initiative;
- Resilient Rivers Water Infrastructure Program – 450GL target for water for the environment, including urban, industrial, mining, and on/off farm water efficiency.
- Murray Darling Basin Plan (efficiency measures), Sustainable Rural Water Use and infrastructure Program, & Restoring our Rivers Act (2023) – *"increase ways to deliver water for the environment to reduce reliance on buybacks"*
- First Nations Water Policy (access to water)
- National Science and Research Priorities

Energy / Storage / Fuels (Including Batteries / Hydrogen / Biofuels

- Powering Australia
  - commitments to support agriculture and carbon farming, transport and energy
  - 43% emissions reduction by 2030; Net Zero by 2050; 82% renewable electricity target

The overlapping nature of the National Science and Research Priorities.

- Powering the Regions Fund – decarbonising existing industries, developing new clean industries, Carbon Capture, Utilisation and Storage (CCUS), and driving ACCUs.
- National Battery Strategy
- First Nations Clean Energy Strategy
- Australia's Future Gas Strategy
- National Hydrogen Strategy
  - Hydrogen Headstart Program - Biohydrogen
- Capacity Investment Scheme to encourage investment in renewables and storage
- Towards a Renewable Energy Superpower Report
- National Energy Transformation Partnership with the states
- Unlocking Australia's Low Carbon Liquid Fuels (LCLF) Opportunity (Future Made in Australia)
- National Science and Research Priorities

Employment, Economic and Regional Resilience

- Future Made in Australia Agenda – enhancement of both major streams of the agenda: *Net Zero Transformation Stream*, and *Economic Resilience and Security Stream*.
- National Reconstruction Fund – priority areas for *Renewables & Low Emission Technologies, Agriculture, Forestry and Fisheries, Transport, Resources and Advanced Manufacturing.*
- Regional Investment Framework for strong and sustainable regions
- Boosting Supply Chain Resilience Initiative
- National Freight and Supply Chain Strategy
- Indo-Pacific Carbon Offsets Scheme - $100M support to climate action in the region
- Australian government programs and partnerships for International Climate Action
- Climate Resilient Agricultural Development and Food Security Program
- National Science and Research Priorities

ANZ BIOCHAR INDUSTRY GROUP — Australian Biochar Industry 2030 Roadmap

- **10 Priority Themes**
- **10 Key Initiatives**

"The Australian Biochar Industry Roadmap is a call to action. It demonstrates and explains the huge potential for growth of biochar production and use in Australia.
Making this potential real will deliver major economic, environmental and social benefits….

…..I look forward to the biochar industry making a major contribution to the emergence of Australia as a Superpower of the net zero world economy. "

Ross Garnaut AC
ANZBIG Patron, May 2023

- **Over 50 Million tonnes/yr** of commercially accessible sustainable biomass residues are **currently being burned, landfilled or under-utilized**.
- **Potential to reduce Australia's net carbon emissions by 10-15%, provide up to 20,000 permanent jobs** (particularly in regional and rural areas), improve soil health and agricultural productivity and return degraded lands to a higher value.

Hurdles and Barriers to a Circular Economy

Identification of Barriers

A variety of biochar bioenergy technologies and applications are commercially available or rapidly approaching commercialisation, however there are challenges that slow down the adoption and progress of the **Circular Economy with Carbon Stewardship**. Below we explore a few of the critical challenges.

Some of the common barriers identified across Australia during consultation for development of the Australian Biochar Industry 2030 Roadmap included:

- **Definitions of '*Waste*' (vs resources)** – both feedstocks and biochar itself too often defined as a waste (including trackable/reportable waste). Linear vs circular systems. Subsequent assessment, tracking, costs and potential waste levy impacts.
- **Definitions of '*Thermal Treatment*' – Combined/collective regulation of all thermal treatment systems - *Incineration /combustion (*linear waste to energy, WtE) and *pyrolysis / gasification* (circular/regenerative WtE).** E.g. ACT complete ban on all new thermal treatment; use of conventional waste hierarchy (alone) in most states.
- **Disproportionate regulation in regards to scale of activity/risk** (same rules can apply for small & large systems, mobile vs stationary, rural/urban etc.). WA leading with positive reforms specifically addressing this.
- **Need for *Fit-For-Purpose* regulation** of biochar quality and use (outcomes based rather than prescriptive regulation of production).
- **Interstate Differences in Regulation** (vs need in carbon commodity markets for harmonisation)
- **Regulation of Mobile Systems Vs Premises-based Systems -** mobile and relocatable systems are commonly in "no man's land" in regards to regulatory fit.

- **Consideration of (and comparison to) *"Business as usual"*** for current management of wasted resources (e.g. open burning) compared to biochar bioenergy (e.g. in regards to air emissions).
- **Lack of awareness** of modern production and soil/non-soil uses of biochar (users and regulators), including appropriate understanding of its place in upcycling and higher order use of resources.

Some of these aspects are explored in detail further below. Key inhibitors to biochar market growth were also assessed as part of the 2023 Global Biochar Market Report (IBI 2024) provided in full in **Appendix 6**, with key findings illustrated in Figure 20.

Figure 20: Extracts from the 2023 Global Biochar Market Report relating to barriers

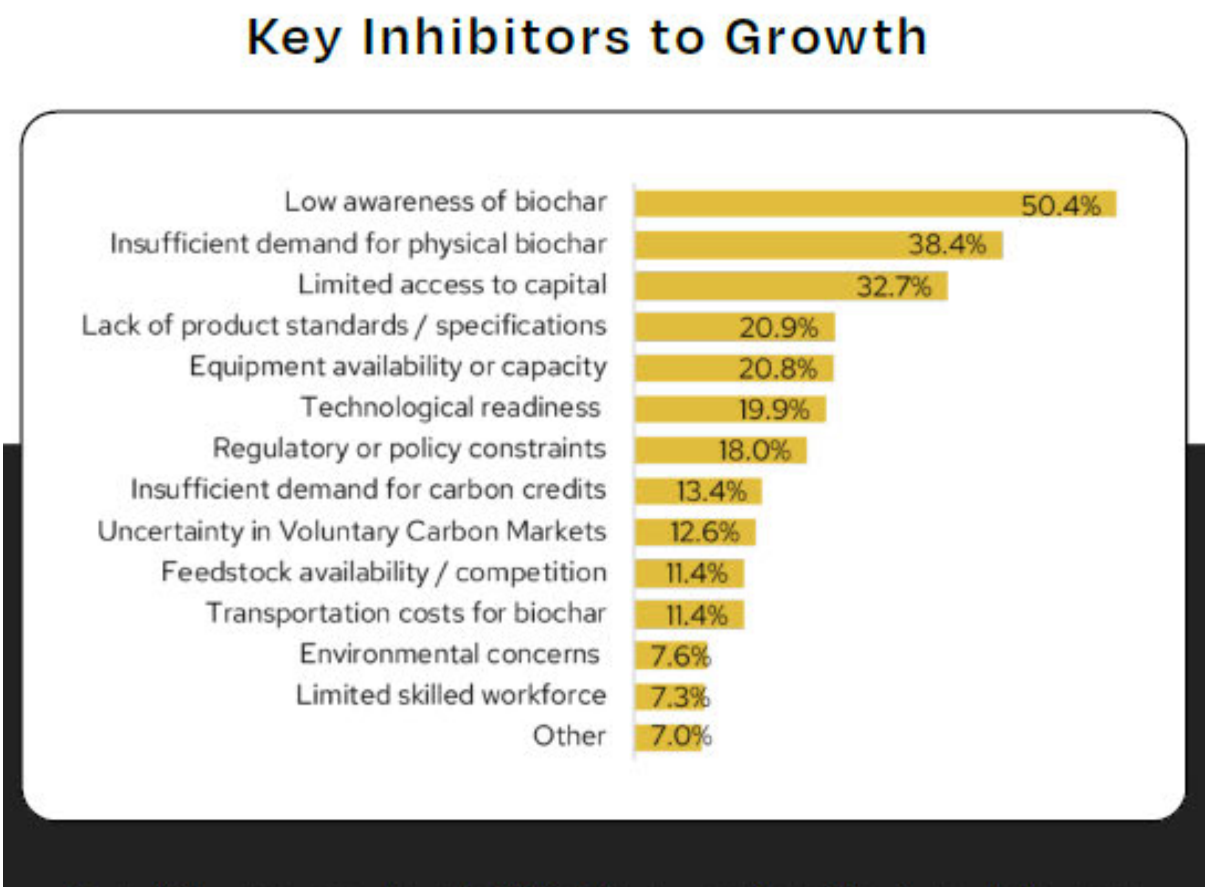


Figure 4. Top responses when asked "What do you perceive as the primary challenges or obstacles to expanding biochar production and use in your country? (Please select up to top three)".

Significant Manufacturing Challenges

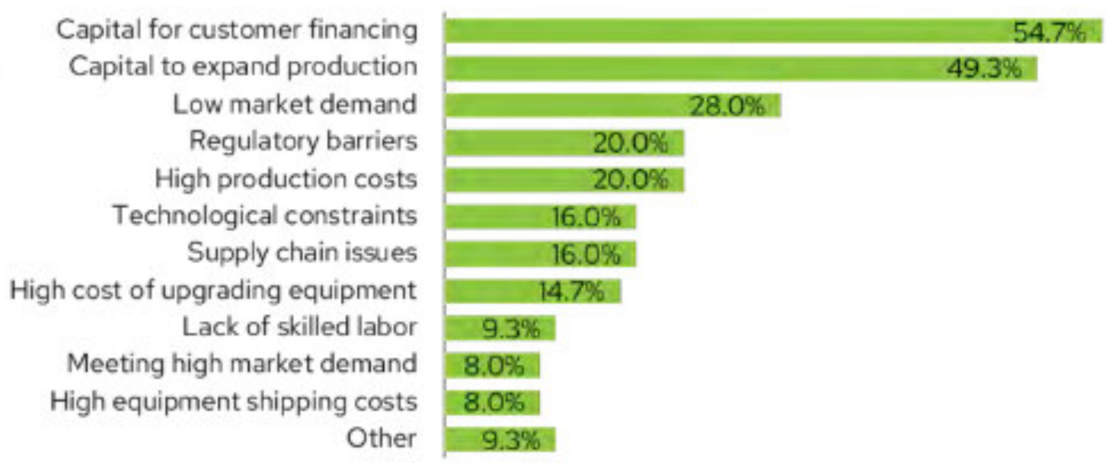


Figure 21. Primary challenges among biochar equipment manufacturers when asked "What are the most significant challenges your company faces in manufacturing biochar equipment? (Please select up to top three)".

Measurement, Reporting, and Verification (MRV) Challenges

Figure 26. Challenges in monitoring, reporting, and verification for biochar carbon removal (BCR) credits reported by carbon industry members when asked "What challenges do you encounter in the MRV process for biochar carbon removal credits? (Please select up to top three)".

Priorities for Biochar Organizations

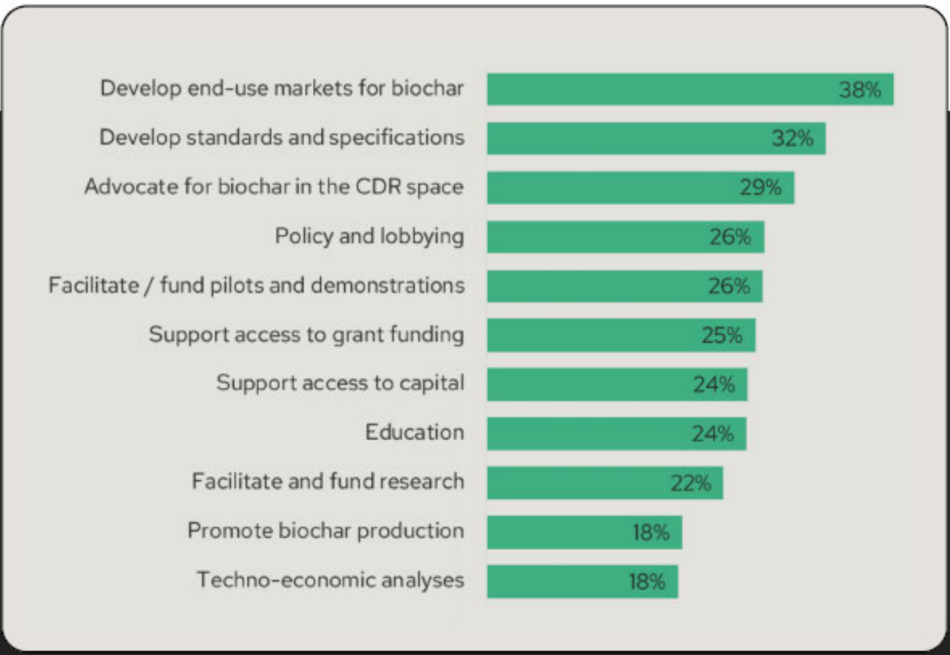


Figure 12. Key priorities for biochar organizations based on responses to "What are the key areas where you think biochar associations should focus their time? (Please select up to top three)".

Key Sourcing Considerations

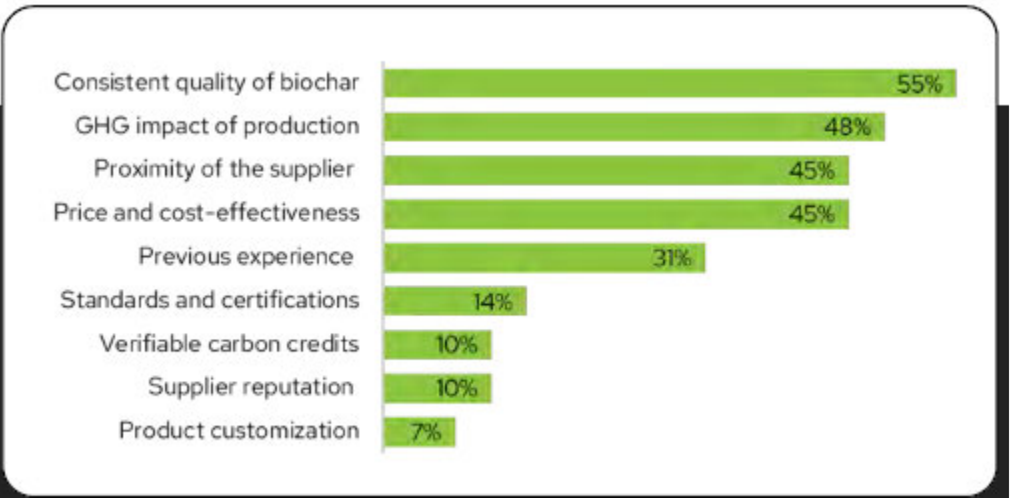


Figure 29. Key considerations among non-agricultural end-users when sourcing biochar when asked "What product specifications do you consider when sourcing biochar? (Please select up to top three)".

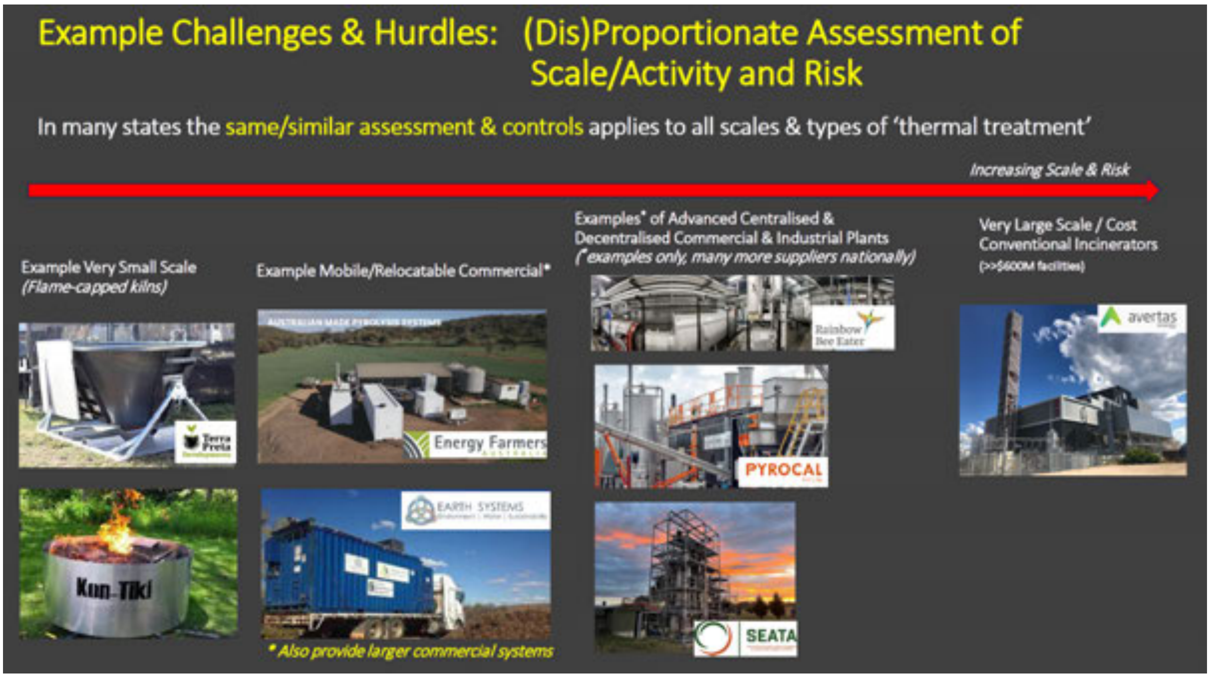
1. Regulatory Constraints

Many industries face relatively complex regulatory hurdles that were originally developed for traditional linear economy models, and in doing so inadvertently hinder circular solutions. For example, restrictive waste classifications can prevent the re-use of materials that could otherwise be valuable in circular systems. Complex and fragmented policies across federal, state, and local levels create uncertainty (and hence investment risk), making it difficult for companies to navigate circular innovations (like biochar) without facing significant barriers, increasing cost and time for approval, and decreasing the appetite for private investment.

Additionally, existing regulations do not differentiate between destructive practices like incineration and sustainable technologies such as pyrolysis used in biochar production. This lack of distinction limits biochar's adoption. A supportive regulatory framework is needed to ensure biochar and similar innovations can thrive, including policies that facilitate end-of-waste classifications, resource recovery, and cross-border regulatory harmonisation.

There is also a significant issue nationally with disproportionate and collective regulation of thermal treatment systems. One size does not fit all - not all thermal treatment is created equal, as illustrated in the figure below. **Proportionate risk-based regulation reflecting scale and risk of activity is crucial (Figure 21)**. The WA Government is reportedly introducing proportionate risk based measures in their new resource recovery framework. **Innovation pathways** and **pilot pathways** for new innovation in production and uses of circular carbon products is also urgently needed, and can provide important immediate measures that can allow/facilitate early adoption of biochar bioenergy systems while broader regulatory reform/upgrades is undertaken.

Figure 21: Example of the Need for Proportionate Regulation by Scale of Activity/Risk



2. Lack of Incentives

Transitioning to a circular economy often requires significant upfront investments in new technologies, infrastructure, and research, which can be a deterrent, especially for smaller businesses. High initial costs can limit widespread adoption of circular practices despite their long-term benefits.

The biochar industry faces significant challenges due to the absence of financial incentives and supportive policy frameworks that promote its adoption at scale. Governments need to play a more active role in providing subsidies, tax incentives, and grants to encourage investment in biochar technologies. Incentives have been successful in accelerating renewables in both Europe (EU Green Deal) and the USA (Inflation Reduction Act and tax credits (e.g. 45V, 45Q)). As an industry in its infancy without the benefits of scale and existing aligned infrastructure support (among many other things a mature industry has), without these financial mechanisms many biochar projects struggle initially to become economically viable, particularly in sectors where biochar could replace highly established, large scale fossil-based products.

Support for research and development is also crucial to reduce costs, improve biochar production efficiency, and open up new market applications. By aligning government resources and policies with the ANZBIG 2030 Roadmap initiatives, a sustainable circular bioeconomy can flourish, providing both environmental and economic benefits.

3. Supply Chain Fragmentation and Coordination Issues

Circular models rely on coordinated systems where materials flow across sectors. However, supply chain fragmentation and logistical complexities make it difficult to create closed loops, particularly for biochar and other sustainable products.

The development of **cross-sector partnerships** to share costs and resources. By working together, multiple industries (e.g. water, agriculture, and energy) can pool their resources to build the necessary infrastructure and create a stable supply chain for biochar production. These partnerships would not only reduce costs but also expand the potential uses for biochar, supporting both environmental and economic goals.

Case Study - Australian Water Sector Opportunities and Barriers to Circular Economy:

The urban water industry of Australia, represented by **Water Services Association of Australia (WSAA)**, prepared the **Help Us Help You** report which explores the opportunities and barriers for Australian water utilities to contribute to the circular economy, as well as national decarbonisation, environmental restoration and liveable cities objectives.

Converting biosolids into biochar is one of the key opportunities identified by WSAA. The paper identifies key barriers that hinder biochar adoption, offering recommendations for overcoming these challenges to enable the water industry to fully leverage biochar technologies.

One of the main challenges highlighted in the report is the **regulatory constraints** on transporting and utilising biosolids for biochar production. Current waste classifications treat biosolids as waste rather than valuable feedstock, preventing easy movement between facilities and significantly increasing costs. Additionally, there is limited infrastructure capable of processing biosolids into biochar at scale, exacerbating the challenge for wastewater treatment facilities to adopt circular practices. These regulatory and logistical hurdles keep the industry from optimising biosolids for biochar production.

Another major issue is the **economic viability** of biochar projects in the water sector. The report indicates that the initial capital investment required to build biochar processing plants is high, and with **current financial disincentives** (i.e. waste levies) or without financial incentives (i.e. ACCUs), many organisations are unwilling or unable to bear the upfront costs.

WSAA proposes **regulatory reforms** that would reclassify biosolids as valuable feedstock rather than waste, allowing for easier transportation and use across sectors. This would lower the costs of biochar production and enable more widespread adoption. Additionally, the report advocates for **financial incentives and subsidies** to reduce the financial burden on organisations investing in biochar technologies. Establishing a market for biochar products, supported by government policies, would further enhance the commercial viability of these projects.

The barriers outlined in the **Help Us Help You** report align closely with the challenges faced by biochar projects in our own submission. Regulatory hurdles, economic viability, and supply chain fragmentation are critical issues that must be addressed to fully realise the benefits of biochar in the circular economy. Our submission builds on the insights from WSAA, proposing further reforms to unlock the potential of biochar and support decarbonisation efforts across multiple industries.

Proposed Solutions – What actions should government take?

Proposed actions to realise the potential for circular carbons are introduced in the preceding sections, and responses/solutions to address key barriers identified above are detailed in the following section *"Government's Role in the Circular Economy"* and within the Australian Biochar Industry 2030 Roadmap (see **Appendix 1**).

Governments' Role in the Circular Economy

Policy and Regulatory Support

Production of biochar has 'touch points' in policy and legislation at both federal and state/territory government levels (WSAA, 2024). Enabling change can be a complex process that needs to consider:

- The appropriate instrument (i.e. regulation, policy or legislative change)
- Scale and regulatory impact
- Alignment with other jurisdictions
- Impact on markets

Key concepts:

- Create circular economies that facilitate regeneration of nature (one of the three critical pillars of circular economy).
- Seek outcomes-based regulatory approaches over prescriptive ones, and proportionate risk-based regulation that reflects the scale, type and actual risk of activities, and which considers potential improvement over current management practices.
- Create circular economies that value feedstocks (resources) over 'wastes' - Adopt the principles of 'End of Waste Codes' and related guidelines/standards to define when a 'waste' becomes a resource.

Recommended Actions:

- Revise definitions relating to 'waste' in legislation.
- Revise definitions relating to 'thermal treatment' in legislation to decouple linear 'single-use' EfW processes (e.g. combustion/incineration for end of life disposal) from circular and regenerative EfW processes (e.g. pyrolysis and gasification of biomass).
- Enable production and usage of biochar to be considered a 'higher order use' or 'higher value use'.
- As an interim measure, enable innovation pathways that facilitate circular economy and climate-positive outcomes, and which define when 'wastes' become resources.

- Integrate with new financial disclosure and sustainability reporting frameworks (e.g. IFRS S1 and S2).
- Reflect scale, type and risk of activities proportionally in policies and regulations.
- Include consideration against 'business as usual'.
- Resource and establish an Australian Carbon Credit Unit (ACCU) method for biochar CDR as a high priority, including addressing existing barriers in GHG inventory and other aspects to facilitate such.
- Support collaborations amongst aligned industries that advocate for similar approaches.
    - For example, requested policy support measures for *Biosolids-derived biochar* (BDB) outlined by WSAA (the peak body for the Australian water industry) in their *Biochar Technical Paper* (**Appendix 4** to this submission) within their submission to CEMAG (Jan 2024) "*Help us Help You – Australian water Sector opportunities and barriers to Circular Economy"*. WSAA requested eight (8) federal policy reforms and seven (7) state reforms. This notably included **resourcing development of detailed rate-based application guidelines for biochars in soil applications** which should be prioritised.
- **Resource and facilitate implementation of the *Australian Biochar Industry 2030 Roadmap*.** It is also noted that the peak body for the Australian water industry (WSAA) has also called for this in their 2024 submission to CEMAG (refer **Appendix 4**).

A couple of the above aspects are discussed in further detail below.

(i) Decoupling Linear Energy from Waste (Combustion/Incineration) from Circular and Regenerative Resource and Energy Recovery (e.g. Biochar Bioenergy)

The **National Waste Policy** provides a nation-wide framework for waste and resource recovery in Australia. **Strategy 5: 'A common approach'** aims to implement a common approach towards waste policy and regulation, particularly in relation to national opportunities to support development of markets for resource recovery and recycling.

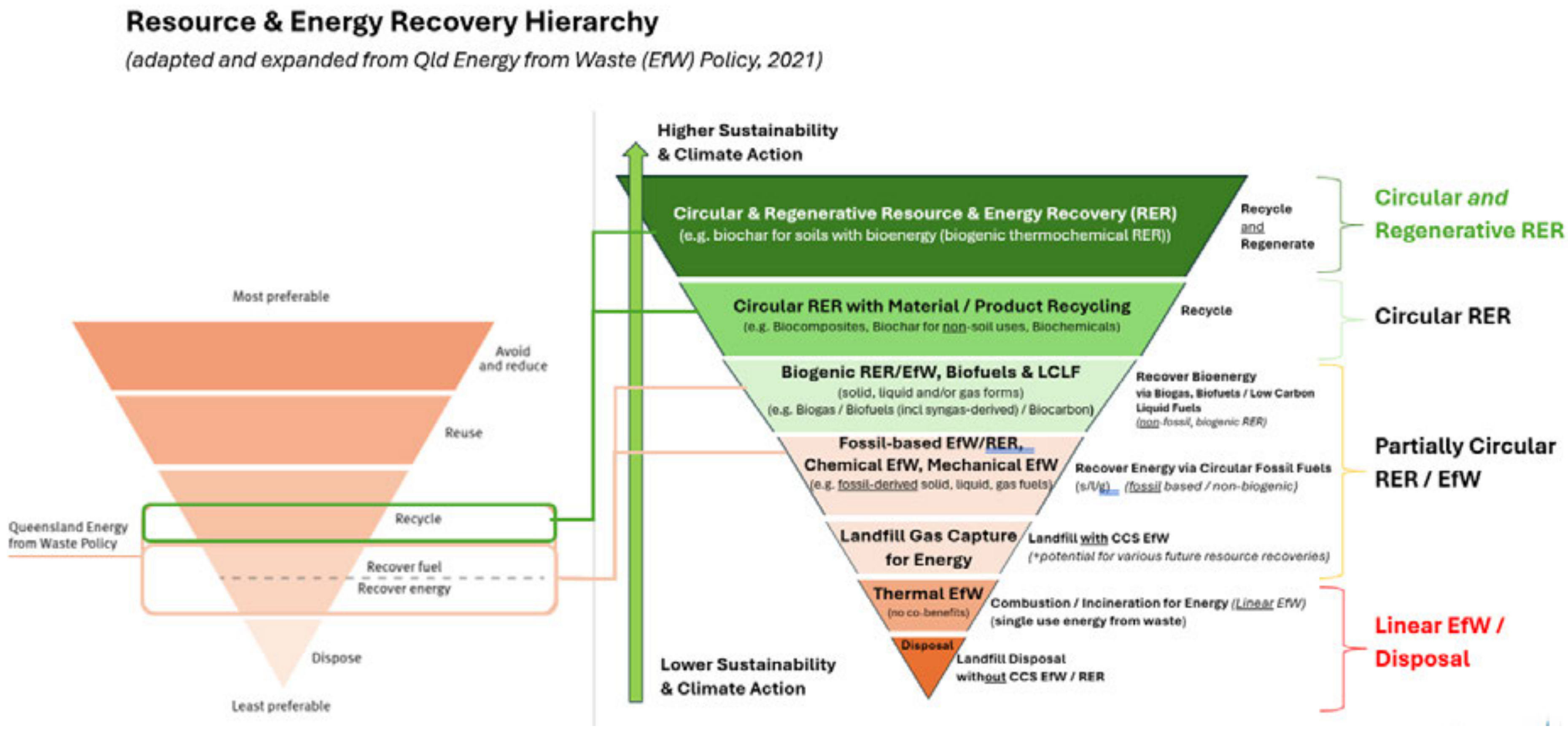
Not all thermal treatment is created equal, especially in terms of sustainability, circularity and climate action performance. Indeed, some are near polar opposites.

A **national framework for resource recovery assessment of thermal technologies,** including biochar production, could enhance alignment with circular economy principles, and enable carbon stewardship through the recovery of energy and materials from biomass and other organic wastes in an appropriate manner.

The **Queensland Energy from Waste Policy** (2021) has established an *energy from waste hierarchy* for residual waste which recognises circular carbon liquids and energy from waste as Higher Order Uses but does not *yet* consider circular carbon solids (biochar) or gases (syngas) for additional resource and energy recovery.

Accordingly, the energy from waste hierarchy for residual waste should be expanded upon to include carbon stewardship by adding **circular and regenerative resource and energy recovery** processes as illustrated in **Figure 22**. This would also assist in recognising the significant differences in thermal treatments, and facilitate decoupling of more circular advanced thermal technologies like biochar production as higher order uses, as separate from conventional linear energy from waste processes such as combustion and incineration. Accordingly, government adoption of concepts such as that shown in **Figure 22** is strongly encouraged

Figure 22: Proposed Updated Waste Hierarchy – recommended for recognition and adoption by government



(ii) Australian Standards and Certification

Creating standards and certification for biochar production and product quality, such as Australian Standards and/or adoption of the ANZBIG Code of Practice[5], is critical to ensuring that biochar production is both sustainable and environmentally responsible. This is consistent with best practices in Europe and the USA, and reflects market feedback as detailed within the 2023 Global Biochar Market Report (see **Appendix 6**).

Standards are required to establish clear guidelines on sourcing biomass, production methods, and the quality of biochar, ensuring that only waste or sustainably sourced organic materials are used. Without such standards, there is a risk that demand for biochar could incentivise unsustainable practices, such as deforestation or the exploitation of land for biomass production, which would undermine its environmental benefits and lead to worse outcomes, including biodiversity loss and increased carbon emissions.

Certification would guarantee that biochar contributes to climate goals by sequestering carbon and enhancing soil health without causing harm to ecosystems. It would also build market confidence, allowing businesses, farmers, and policymakers to adopt biochar with the assurance that its use aligns with broader sustainability and circular economy objectives.

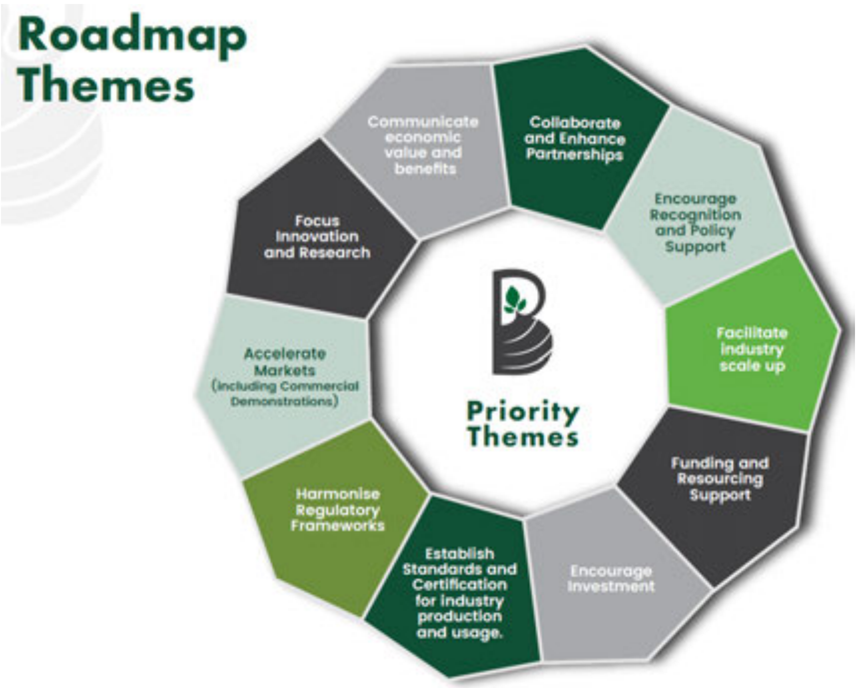
By ensuring transparency and traceability in biochar production, these standards would prevent greenwashing and promote truly sustainable practices.

It is noted that a proposed **Australian Standard** for biochar quality and grading/classification has recently been proposed under an "Accelerated Pathway" mechanism within Standards Australia. In light of (and combined with) other policy and regulatory mechanisms such as *End of Waste Codes,* decoupling policies to separate circular and linear thermal treatments, and proposed ACCU methods for biochar, an Australian Standard for biochar quality represents a very **significant** opportunity to align and integrate multiple policy mechanisms to genuinely facilitate circular economy, and should be supported by government wherever possible (including resourcing development).

[5] ANZ Biochar Industry Group, *Code of Practice for the Sustainable Production and Use of Biochar in Australia and New Zealand*, November 22, 2021 (Version 1.0) – available here.

(iii) Facilitate Implementation of the Australian Biochar Industry 2030 Roadmap

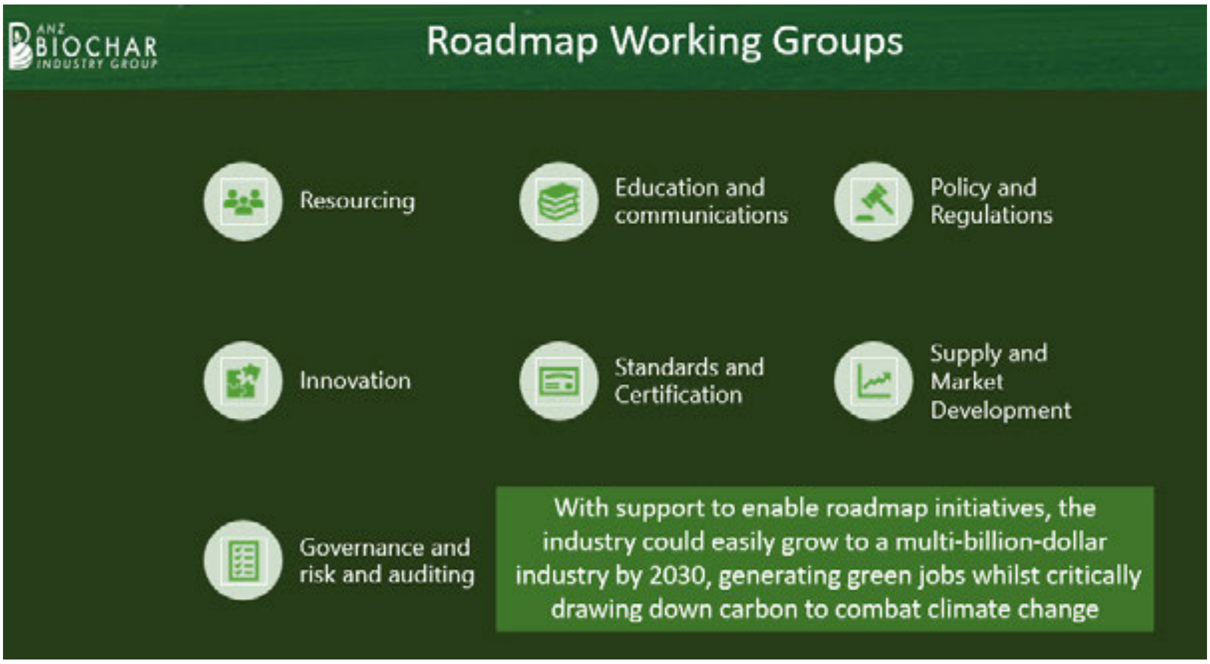
The Australian Biochar Industry 2030 Roadmap comprises **ten (10) key priority themes and ten (10) key initiatives** contributing to multiple priority themes. The themes include:



The supporting initiatives include

1. Launch the Australian Biochar Industry Roadmap and **fund Scale-Up Plan**
2. **Improve Stakeholder Awareness and Education** of Biochar Uses and Benefits
3. **Integrate and Optimise Industry and Regulatory Frameworks**
4. **Support Biochar Commercial Demonstration Trials**
5. Leverage Carbon Emission Reduction and CO_2 Removal Opportunities
6. Encourage Beneficial Use of Waste Biomass
7. Drive Beneficiation and Increased Value of Biochar and Co-Products
8. **Safeguard Responsible Consumption and Production of Biochar**
9. **Support Government, Utility, and Industry Procurement Practices**
10. **Drive Export** of Australian Biochar Innovation Internationally

Many of the initiatives have significance and alignment with government policy goals as noted earlier in this submission, including internationally. For example, leveraging the significant power of **government procurement** positively to support circular and regenerative industries can provide offtake security for emerging industries and should be prioritised. Supporting Initiative 10 could assist the Australian government to meet commitments to support climate action in the Indo-Pacific region (e.g. COP28 commitments). The ANZ Biochar Industry Group (ANZBIG) has established working groups to help facilitate implementation of the roadmap and is currently volunteer driven. **Government support could significantly accelerate implementation and is encouraged.**



Conclusion

Carbon stewardship presents a transformative opportunity for Australia to transition toward a circular economy and achieve its net-zero emissions goals. As demonstrated throughout this submission, carbon stewardship through biochar production, supported by other circular carbons, offers a unique ability to convert organic waste into a valuable, carbon-sequestering resource, positioning it as a powerful tool in tackling some of Australia's most pressing environmental and economic challenges.

Key Opportunities for Biochar

Biochar aligns seamlessly with the core principles of a circular economy, offering a closed-loop solution that eliminates waste, circulates resources, **and regenerates nature**. Its diverse applications span across sectors, including agriculture, water, construction, waste management, and energy. By enhancing soil health, improving water retention, and reducing the need for synthetic fertilizers, biochar plays a crucial role in advancing sustainable agriculture, which is vital to supporting food security and climate resilience. In construction, biochar can be used in green building materials like concrete, reducing carbon footprints while enhancing material strength and longevity.

Moreover, biochar contributes significantly to carbon sequestration, locking carbon in a stable form for hundreds to thousands of years. This not only helps reduce atmospheric CO_2 levels but also mitigates the effects of climate change by regenerating ecosystems, improving biodiversity, and restoring degraded lands, such as in post-mining rehabilitation projects. The synergies between biochar production and the broader bioeconomy – including renewable energy generation through syngas – further reinforce its role as a cornerstone in Australia's low-carbon future.

Environmental and Economic Benefits

Biochar's environmental benefits are multifaceted. By converting organic waste materials – such as agricultural residues, forestry by-products, and even municipal biosolids – into a carbon-rich product, biochar not only diverts waste from landfills but also reduces harmful methane emissions and other pollutants. Its use as a soil amendment improves nutrient retention, water holding capacity, and microbial activity, leading to remediation of degraded lands, increased agricultural productivity and long-term soil fertility. Additionally, biochar's application in water filtration, bioplastics, and industrial processes further extends its environmental impact by offering sustainable alternatives to traditional materials and improving resource efficiency.

Economically, biochar's ability to enhance agricultural productivity and reduce waste management costs provides significant benefits to farmers, businesses, and local economies. The potential for carbon credits and financial incentives through programs like Australia's Carbon Credit Units (ACCUs) also presents new revenue streams for biochar producers and users, further supporting its integration into national climate strategies. As biochar practices become more widespread, they will contribute to Australia's efforts to achieve a low-carbon economy while promoting sustainable development and job creation, particularly in regions undergoing economic transition.

ANZBIG (2024) indicatively estimated that the **potential economic benefit of converting Australia's >50Mtpa of biowastes into biochar bioenergy** to assist Australian Agriculture could result in a total of over **$12.5 billion worth of benefits *every year*, reduce Australia's net emissions by 10-15% and provide up to 20,000 jobs including in regional and rural areas**:

- **$5-7.5B/yr** worth of biochar as a physical commodity
- **$3B/yr** worth of biochar CO_2 removal carbon credits (B-CDR)
- **$2B/yr** worth of agricultural productivity gains (e.g. yield)
- **$16.5M/yr** worth of renewable energy
- **$90M/yr** worth of soil carbon growth (plus significant reductions in GHG released from agricultural soils through use of biochar, ranging 12-50%)
- **$32M/yr** worth of water savings (through a conservative 0.5% increase in soil carbon across 10% of agricultural lands).

Biochar offers the potential to drive job creation, particularly in regional and rural areas, by developing industries involved with biochar production and application. The expansion of the biochar industry can also attract significant investment in green technologies, providing new opportunities for economic growth and innovation in sectors transitioning away from traditional industries such as mining. Furthermore, biochar's use in industrial symbiosis, where waste from one industry becomes the input for another, highlights its potential to reduce resource consumption and waste generation across supply chains.

Actions Needed to Overcome Barriers

Despite these clear benefits, several barriers must be addressed to fully unlock biochar's potential. The lack of clear regulatory frameworks that recognise and facilitate advanced thermal treatments, like pyrolysis for biochar production, as circular and regenerative processes, distinct from traditional linear processes such as combustion and incineration, hinders the development of sustainable biochar markets and prevents it from being fully integrated into Australia's circular economy and carbon reduction strategies. Resource recovery frameworks need to recognise these important differences in higher order use, and establish suitable protocols to determine **when and how waste from one sector becomes a *resource* to another** in order to facilitate genuine circular economy, including measures such as ***'End of Waste Codes'***.

Other challenges currently being faced are the initial cost of establishing biochar production facilities, particularly pyrolysis plants, the absence of biochar standards or certification, market development, and the definition of waste also hampers widespread adoption. Additionally, awareness among key stakeholders, including farmers, industry leaders, and policymakers, remains limited.

To overcome these barriers, government action is essential. Providing financial incentives, such as grants, subsidies, tax incentives and carbon crediting measures (ACCUs) for biochar production and application, will help lower the entry cost for businesses and farmers. It is noted that well-advanced proposed method for biochar CDR ACCUs was proposed to the government in July 2024 by a cross-industry working group. The proposed biochar method was not shortlisted for development in 2024-25, but recognised for readiness should GHG inventory and other barriers (including internal resourcing) be addressed. Measures to address these should be resourced, facilitated and accelerated. The government should also facilitate measures to encourage measured benefits of biochar in meeting the emerging requirements for Financial Disclosure Reporting (FDR) for climate (mandatory) and sustainability (voluntary) commencing from 2025 onward. The benefits of biochar to aid improved reporting for Australia's "report card" toward the UN Sustainable Development Goals (SDGs) should also be considered. Establishing national standards and certification for biochar as a soil amendment and carbon sequestration tool will create market confidence and drive adoption. Furthermore, integrating biochar into Australia's broader environmental policy frameworks, such as the National Waste Policy and climate policies, will ensure it becomes a central component of the country's sustainability efforts.

Education, awareness and outreach programs are equally important, particularly for an emerging circular industry. Government programs and industry partnerships should be established to raise awareness of biochar's benefits and demonstrate its practical applications across sectors like agriculture, construction, and land rehabilitation. Indigenous involvement must also be prioritised, ensuring that biochar projects respect and incorporate traditional knowledge, while protecting cultural and intellectual property. Indigenous land management practices, particularly controlled burns to reduce wildfire risks, align well with biochar production and can play a crucial role in regenerating ecosystems and enhancing soil health.

Path Forward

By fostering collaboration between government, industry, Indigenous communities, and research institutions, Australia can unlock the full potential of biochar. This will require a coordinated effort to remove regulatory barriers, provide financial support, and raise awareness across sectors.

With the right policies and incentives in place, biochar can contribute meaningfully to the nation's circular economy, reducing waste, enhancing soil and ecosystem health, and driving carbon sequestration efforts.

The *Australian Biochar Industry 2030 Roadmap* provides a shovel-ready resource to aid government, industry and the community to accelerate the awaiting opportunity, and has been costed to do so at a **fraction** of the commitment the government of Denmark has recently allocated to turbo-charge the biochar industry there (over USD$1.3B). Notably, here in Australia **external funding support has *not* yet been allocated by government toward implementing Australian Biochar Industry 2030 Roadmap and is encouraged**. In conclusion, biochar offers Australia a unique, scalable, measurable and "shovel-ready" solution to many of its environmental, social, and economic challenges. As the country strives to meet its net-zero targets and build a more sustainable, resilient economy, biochar's ability to transform waste into value and sequester carbon makes it an essential tool for the future. By taking the necessary steps to overcome current barriers, Australia can position itself as a global leader in biochar innovation, driving progress towards a circular economy that benefits both people and the planet.

Appendices/Supporting Information

As requested, provided below is a list (and website links) of appendices/references or other supporting info supplied with this submission:

Appendices:

Appendix 1: ANZBIG 2024, Australian Biochar Industry 2030 Roadmap (V2.0)

Appendix 2: Martin R (GlobalPSC) & Bagnall C(SEATA) 2024, *"Towards a Circular Economy and Net Zero Through Carbon Stewardship"*, presentation to the 2nd Annual International Conference on *Circular Economy for Climate and the Environment* (CECE, Sydney 2024).

Appendix 3: ANZBIG 2024 presentation, *"Australian Biochar Industry 2030 Roadmap"* - A multi-billion dollar industry removing carbon, increasing revenue and increasing agricultural GVP.

Appendix 4: WSAA 2024, Extract (biochar technical paper) from WSAA submission to CEMAG, "*Help us Help You – Australian water Sector opportunities and barriers to Circular Economy*"

Appendix5: Factsheets:

5a) ANZBIG Biochar Fact Sheet

5b) WSAA 2023, Information Factsheet: '*Biochar 2 Batteries' Project*

Appendix 6: IBI 2024, *2023 Global Biochar Market Report*

Appendix 7: Taylor P and Joseph S 2024, *A Farmer's Guide to the Production, use and application of biochar*", via ANZBIG, **includes updated case studies**. **Note**: *Provided **commercial-in-confidence,** not for wider distribution (commercial product).*

Appendix 8: Robb S and Joseph S 2020, Biochar User's Report: *"A report on the value of Biochar and Wood Vinegar"*, presenting economic case studies and **Net User Benefits** ($$ per tonne of biochar).

Appendix 9: ANZBIG 2024, presentation: *"Circular and Regenerative Bioenergy: Pathways for CO2 Removal and Renewable Energy for Net Zero via the Australian Biochar Industry 2030 Roadmap"*, Australian Bioeconomy Conference 2024, Australian Industrial Ecology Network.

Other References:

1. Joseph & Cowie et al 2021, *How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar*
2. Downie.A & Van Zwieten.L, 2010, *"Terra Preta Australis: Reassessing the carbon storage capacity of temperate soils"*, presents an assessment of indigenous biochar production in Australia for over a thousand years.
3. WSAA 2024, **full submission** to CEMAG, "*Help us Help You – Australian Water Sector Opportunities and Barriers to Circular Economy*"
4. **Related GlobalPSC Reports and Submissions** (available upon request):
    - NSW Parliamentary Inquiry into Mine Rehabilitation 2024
    - Residues Utilisation and Stewardship Strategies Report
5. **Other ANZBIG Submissions to Government** and related documents available via the ANZBIG website ("Resources" page https://anzbig.org/resources/) or directly from ANZBIG upon request:
    a. *– ACCU Method EOI (ANZBIG / Cross Industry Working Group Submission)*
    b. *ERF Soil Organic Carbon Method Review (now ACCU Scheme)*
    c. *ERF CCS/CCUS Method Scoping Paper*
    d. *Net Zero Transport and Infrastructure Sectoral Plan 2024*
    e. *Climate Change Authority 2024 Issues, Targets, Pathways and Progress*
    f. *SA Government Parliamentary Inquiry into Biochar (and responses)*
    g. *Australian Bioenergy Roadmap*
    h. *Australian Technology Investment Roadmap*
    i. *Queensland Draft End of Waste Code for Biochar*
    j. *NSW EPA Energy From Waste Policy Statement*
    k. *Greenhouse Gas Protocol (GHGP) 2022*
    l. *ANZB Biochar Conference Proceedings (2017, 2018, 2021)*