North East NSW Forestry Hub

Preliminary comparison of pyrolysis against full-combustion of CCA treated hardwood timber

Batch Scale Preliminary Test

Final Report

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December 2025

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1. Laboratory Certificate of Analysis – Total Concentrations
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List of Abbreviations / Acronyms

Abbreviations / Acronyms	Definition
ad	Air Dried
ar	As Received
db	Dry Basis
daf	Dry Ash Free Basis
ANZBIG	ANZ Biochar Industry Group
CCA	Copper, Chrome, Arsenic
CDR	CO_2 Removal
COP	Code of Practice (ANZBIG)
EBC	European Biochar Certificate
FBR	Fluid Bed Reactor
GHG	Green House Gas
NEN-FH	North East NSW Forestry Hub
Qld EOW Code	Queensland End of Waste Code For Biochar
XRF	X-Ray Fluorescence

1. Introduction

1.1 Project Aim & Objectives

To quantify and compare the environmental benefits of subjecting treated hardwood timber by advanced thermal treatment (pyrolysis) rather than full combustion.

1.2 Background

Treated timbers currently present multiple regulatory challenges for full-combustion thermal treatment systems (incineration), including linear waste to energy systems (conventional bioenergy). Alternative solutions are of interest to provide a safer, greener and economical alternative to current conventional options, with other co-benefits as outlined below.

Treated timbers may include notable ingredients problematic for conventional full combustion systems, such as:

- CCA (Copper, Chrome, Arsenic) compounds *(the focus of this preliminary study)*
- Copper compounds (e.g. copper carbonate hydroxide)
- Boron compounds
- Sodium nitrite
- Fungicides (e.g. Tebuconazole) and other organic/organo-chlorine residues (e.g. herbicides, pesticides etc.). These may contain halogens such as chlorine which have potential to form problematic organic compounds when combusted, such as dioxins and furans.

Note: dot points 3 to 5 above were beyond the scope of preliminary investigations undertaken in this initial study. Dot point two was considered only at high level through total copper analysis.

Conventional pyrolysis thermal treatment shows potential to address key technical challenges for treated timbers faced by combustion (including heavy metals and organic residues constituents such as pesticides,etc.) in a safe and environmentally friendly manner, whilst also offering potential for carbon credits and far improved circular economy co-benefits. **A significant portion of heavy metals within the feedstock is expected to report to solid carbon chars rather than reporting to air emissions as currently occurs with combustion-based systems**, and research indicates are typically bound (less leachable than in treated timber feedstock). Emissions controls are utilised for volatile metals if present.

Solid carbon biochars produced from pyrolysis can be tested and graded for potential use in multiple circular economy applications as substitutes for fossil carbon, either as industrial-grade carbons for non-soil uses (e.g. if metals content is elevated), or in certain soil applications where testing can demonstrate safe capacity to do so.

Advanced thermal treatment systems show additional promise to provide both the solid carbon biochars as well as a syngas capable of use in renewable energy (power, heat) and/or for potential derivatives such as hydrogen, high grade CO_2. It is noted that conventional systems typically produce liquid products (tars, oils, resins, wood vinegar), however these can be problematic and the proposed system in this proposal does not produce any liquid products, it produces biochar and syngas products only.

This project will help clarify the potential of advanced thermal treatment to address some of the key technical challenges faced with treated timbers in full combustion processes (primarily heavy metals and organic/halogenated residues). This is proposed through a bench/batch scale test on a small representative sample.

If the test indicates positive potential, further staged investigations can be considered in a progressive "walk-jog-run" approach.

1.3 Scope of Work

- **Batch/'bench' scale test** to thermally deconstruct a small representative sample of CCA treated hardwood timber (refer details below) for advanced thermal treatment (pyrolysis using chemical and thermal looping utilising a fluid bed reactor), and for full combustion.
  - As noted above the advanced technology used produces biochar and syngas products only, no problematic liquid phase outputs/wastes (tars, oils, resins).
  - At batch/bench scale, the feedstock material and biochar product are analysed (only), and gas outputs (syngas) is calculated by difference.
- **Laboratory Analysis** – One (1) feedstock sample, One (1) biochar sample and one Ash Residue from full combustion for:
  - Proximate Analysis (moisture, ash, volatiles, fixed C content)
  - Ultimate Analysis (C H H N O S content)
  - Elemental Analysis (total concentrations) for targeted heavy metals (CCA, B and others) and key halogens (Cl, F, Br)
  - High-level Analysis of expected syngas concentrations (calculated by difference)

Whilst not required within the scope of the contract works, our team has additionally provided the following tests within the approved budget to complement the above scope works:

- **Preliminary Leaching tests** of metals (focused on CCA) using an economical introductory test (Australian Standard Leaching Procedure, ASLP) to indicate whether further leaching investigations are warranted (eg via more aggressive leaching methods such as TCLP).

1.4 Key Assumptions & Limitations

- **Preliminary Investigation/Limited Scope** – By design, the study was specifically a *preliminary investigation* using batch scale technology (fluid bed reactor). It seeks to assess the *potential* for deeper investigations via a justified progressive/staged approach.
    - Notwithstanding this, the batch scale technology is a fair and reasonable representation of expected pyrolysis process conditions for biochar product at field scale.
    - Fluid bed reactors have been utilised at industrial scale in similar applications for thermal deconstruction of biomass.
- **Limited Analysis** - Whilst obtaining a representative sample was sought as far as practicable, the following limitations are notes:
- **Limited data set-** Whilst representative sampling was undertaken, preliminary scale lab testing of biochar involved a single result for each parameter. These seek to justify investment in further investigations that increase sampling and lab results data sets.
- **Syngas Estimation** – batch scale technology provides biochar analysis and syngas is estimated by calculation (by difference). Future investigations using *field-scale* technology can measure syngas quality and is designed to confirm these preliminary stage syngas estimations.
- **Sufficient Combustion Ash Sample Quantities** – combustion ash residue based on preliminary literature review was assumed at 1-4% of infeed mass. Actual obtained was at the lowest end of this and subsequently required more processing to supply sufficient sample volumes for laboratory analysis (with subsequent increased time requirements).

Care is required in analysing results and extrapolating conclusions from preliminary investigation. Accordingly, this has been considered in making appropriate and suitably justified recommendations for progressive investigation detailed in **Sections** Error! Reference source not found. **and** Error! Reference source not found..

2. Methodology

2.1 Sample Preparation

The batch scale apparatus required CCA treated timber sized to <20mm. Due to supplier limitations, sliced CCA logs were delivered which required further chipping by hand to the required size, which was then mixed to form a representative head sample.

Plates 1-4 below show:

1. "As Received" (ar) CCA treated timber log slices;
2. Chipped pieces derived from the ar log slices and mixed to form a representative head sample feedstock for all testwork.
3. **Biochar sample** made from (2) above
4. **Combustion ash sample** made from (2) above.

Plate 1: CCA treated timber logs as received (ar).

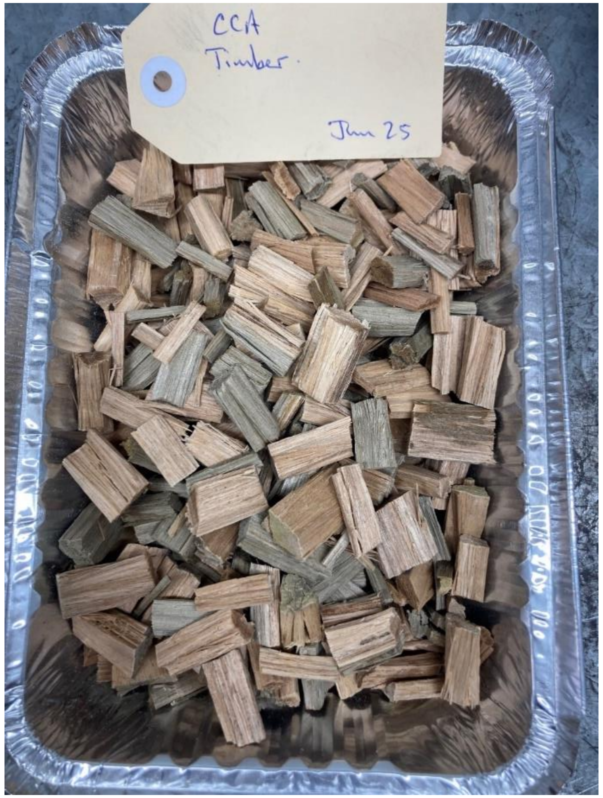


Plate 2

Plate 3

Plate 4

Plate 2: Chipped CCA treated timber pieces mixed to give a representative feedstock head sample

Plate 3: Biochar sample made from pyrolyzed CCA treated timber chips at 400˚C

Plate 4: Combustion ash sample of CCA treated timber pieces

2.2 Thermal Decomposition – Pyrolysis (FBR Batch Scale Plant)

The pyrolysis testwork was undertaken using a batch scale Fluid Bed Reactor (FBR) processing a feedstocks sample size of approximately 0.3kg. A bed temperature of 400°C was selected to maintain sufficient operating margin below 450°C, above which vaporisation of elemental arsenic is reported to rapidly increase, and to minimise volatilisation of arsenic trioxide (As_2O_3), which volatilises between 300-500°C. Arsenic pentoxide decomposes to trioxide at 315°C.

Plate 5: Photo of the FBR Batch (Bench) Scale Plant.

2.3 Thermal Decomposition – Combustion

Complete combustion tests were completed in a muffle furnace due to the light friable nature of the ash, otherwise it would have been blown out of the FBR. The ash content of this hardwood (Blackbutt) was about 1% by mass, therefore accurate measurement of the residual ash was necessary.

2.4 Laboratory Analysis

The solid samples were submitted to ALS ACIRL laboratory in Brisbane for analysis.

3. Results

3.1 Proximate and Ultimate Analysis

Laboratory results for proximate and ultimate analyses are presented in Table 1.

Laboratory results for ash analysis (via XRF) and for Halogens and Other Metals & Trace Elements are presented in Tables 2 and 3 respectively.

Detailed laboratory analysis reports are provided in Appendix 1.

Key mass balance figures from the testwork:

1. **Moisture:** 15.3% 'ar'
2. **Yield to biochar:** 29.6% 'ar' basis or **35.0% 'db'**
3. **Yield to ash:** 0.91% 'ar' basis or **1.08% 'db'**

Table 1: Results of Proximate & Ultimate Analysis

Analyte Group	Analyte	Units	Results		
			CCA Timber (AR)	CCA Timber Biochar	CCA Timber Combustion Ash
Proximate Analysis	Moisture	% (db)	6.8	2.8	0.0
	Ash	% (ad)	1.2	3.1	100.0
	Volatile Matter	% (ad)	82.4	22.9	0.0
	Fixed Carbon	% (ad)	16.4	**74.0**	0.0
	Calorific Value (gross)	MJ/kg (db)	19.09	30.53	0.0
Ultimate Analysis	Carbon	% (daf)	49.8	**83.7**	
	Hydrogen	% (daf)	5.66	3.09	
	Oxygen	% (daf)	44.2	13.1	
	Nitrogen	% (daf)	0.07	0.15	
	Sulphur	% (daf)	0.23	<0.01	

Table 2: Ash major components

Analyte Group	Analyte	Units	Results		
			CCA Timber (AR)	CCA Timber Biochar	CCA Timber Combustion Ash
Ash Analysis (XRF)	Silicon as SiO_2	%	70.1	9.6	21.0
	Aluminium as Al_2O_3	%	23.0	1.8	3.3
	Iron as Fe_2O_3	%	2.32	1.08	1.52
	Calcium as CaO	%	0.40	17.6	42.9
	Magnesium as MgO	%	0.26	8.2	18.1
	Sodium as Na_2O	%	0.21	1.04	2.01
	Potassium as K_2O	%	1.9	3.0	5.6
	Titanium as TiO_2	%	1.2	0.2	0.5
	Manganese as Mn_3O_4	%	0.005	0.52	0.97
	Phosphorus as P_2O_5	%	0.13	0.68	1.30
	Sulphur as SO_3	%	0.24	5.8	2.10
	Barium as BaO	%	0.189	0.074	0.28
	Strontium as SrO	%	0.065	0.151	0.284
	Zinc as ZnO	%	0.016	0.072	0.092
	Total	**%**	**100.04**	**49.82**[1]	**99.56**

Table 3: Minor components

Analyte Group	Analyte	Units	Results		
		(db)	CCA Timber (ar)	CCA Timber Biochar	CCA Timber Combustion Ash
Halogens	Chlorine	**%**	<0.01	<0.01	<0.01
	Fluorine	**mg/kg**	<2	<2	**2**
Other Metals & Trace Elements	**Boron**	mg/kg	**2**	**12.0**	**165**
	Selenium	mg/kg	<0.1	**0.7**	**2.2**
	Molybdenum	mg/kg	<0.1	<0.1	**5.5**
	Manganese	mg/kg	**9.5**	**27.0**	**521.3**
	Barium	mg/kg	**2.8**	**6.4**	**44.1**
	Beryllium	mg/kg	<0.1	<0.1	**0.2**
	Cobalt	mg/kg	<0.1	<0.1	**1.5**
	Lithium	mg/kg	<0.1	<0.1	**1.1**
	Antimony	mg/kg	**1.5**	**19.2**	**244.4**
	Tin	mg/kg	<0.1	**0.20**	**0.2**
	Uranium	mg/kg	<0.1	<0.1	**0.2**
	Vanadium	mg/kg	**1.4**	**3.1**	**70.2**
	Thorium	mg/kg	<0.1	<0.1	<0.1
	Thallium	mg/kg	<0.1	<0.1	<0.1
	Strontium	mg/kg	**15.0**	**42.6**	**479.6**

[1] XRF analysis expressed as oxides should add to ~100% - result TBC.

3.1.1 Mass Balance

Mass balance outcomes for major components via pyrolysis to biochar and for combustion are presented in Tables 4 and 5 respectively.

Further details for the entire mass balance (major and minor components) is provided in Appendix 2.

Table 4: Organic Components - Biochar

Mass Balance

Pyrolysis			25/018	25/019	(calc.)
Rev 3 *20-Nov-25*			**CCA Timber** IN (s)	**Biochar** OUT (s)	**Raw Syngas** OUT (g)
Overall Mass Recoveries		% ad	100.0%	35.0%	65.0%
		% db	100.0%	36.1%	63.9%
	Moisture	mass %	100.00	15.00	85.00
	Carbon	mass %	100.00	61.36	38.64
	Hydrogen	mass %	100.00	19.93	80.07
	Nitrogen	mass %	100.00	78.23	21.77
	Sulfur	mass %	100.00	1.59	98.41
	Oxygen	mass %	100.00	10.82	89.18

Table 5: Organic Components - Combustion

Mass Balance

Combustion			25/018	25/020	(calc.)
Rev 3 *20-Nov-25*			**CCA Timber** IN (s)	**Ash** OUT (s)	**Combustion Off-gas** OUT (g)
Overall Mass Recoveries		% ad	100.0%	1.1%	98.9%
		% db	100.0%	1.2%	98.8%
	Moisture	mass %	100.00	0.00	100.00
	Carbon	mass %	100.00	0.00	100.00
	Hydrogen	mass %	100.00	0.00	100.00
	Nitrogen	mass %	100.00	0.00	100.00
	Sulfur	mass %	100.00	0.00	100.00
	Oxygen	mass %	100.00	0.00	100.00

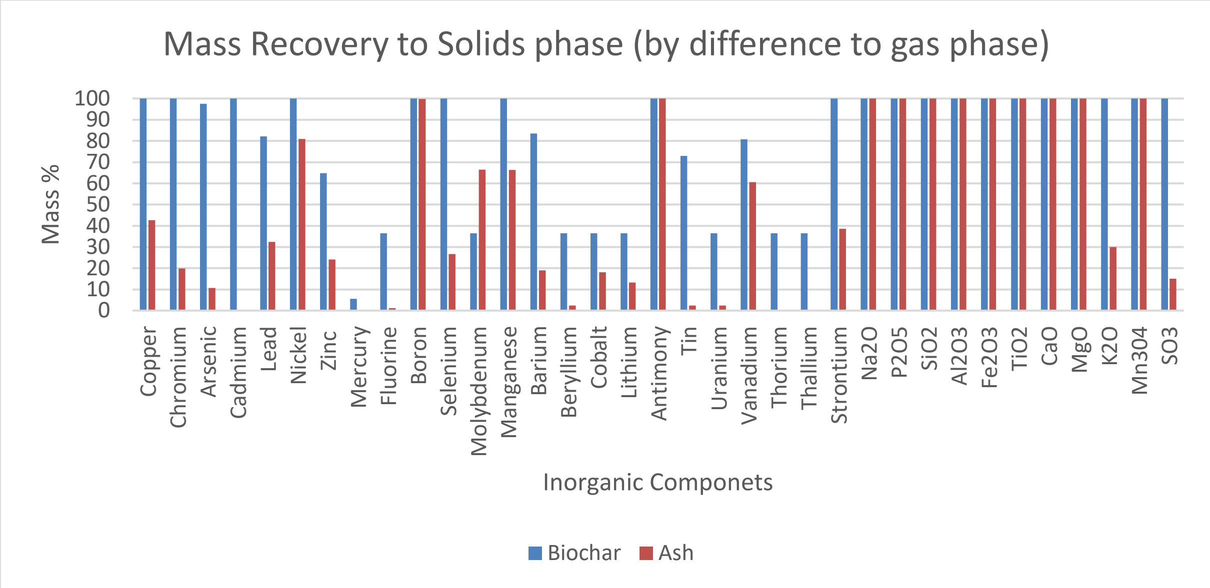


Figure 1: Mass recovery of inorganic components to solid phase.

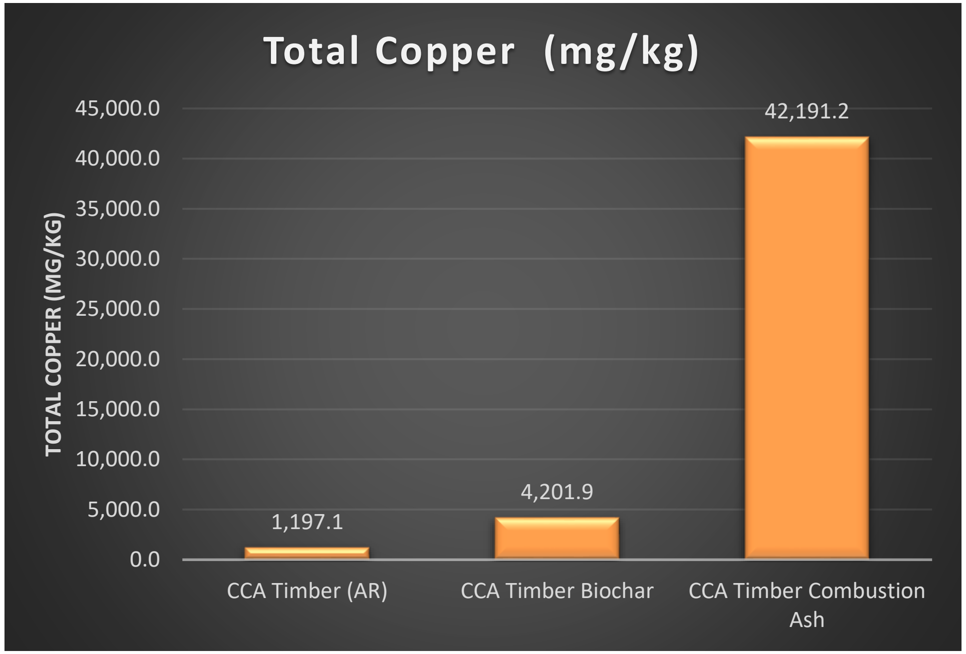
Pyrolysis was operated at 400°C, so the volatile metals substantially remained in the solid phase (biochar) except for Hg. In comparison combustion was run at 900°C, which as expected resulted in high volatisation of metals. Of particular interest in this case is Cu, Cr and As (CCA), with high mass recovery to biochar fraction, hence low emission to the gas phase and therefore not creating another waste stream to deal with, i.e. spent scrubbing liquors. Biochars containing these metals could be ideal as carbonaceous additions to lead-zinc smelts such as Glencore at Mt. Isa (QLD) or Nystar at Port Pirie (SA).

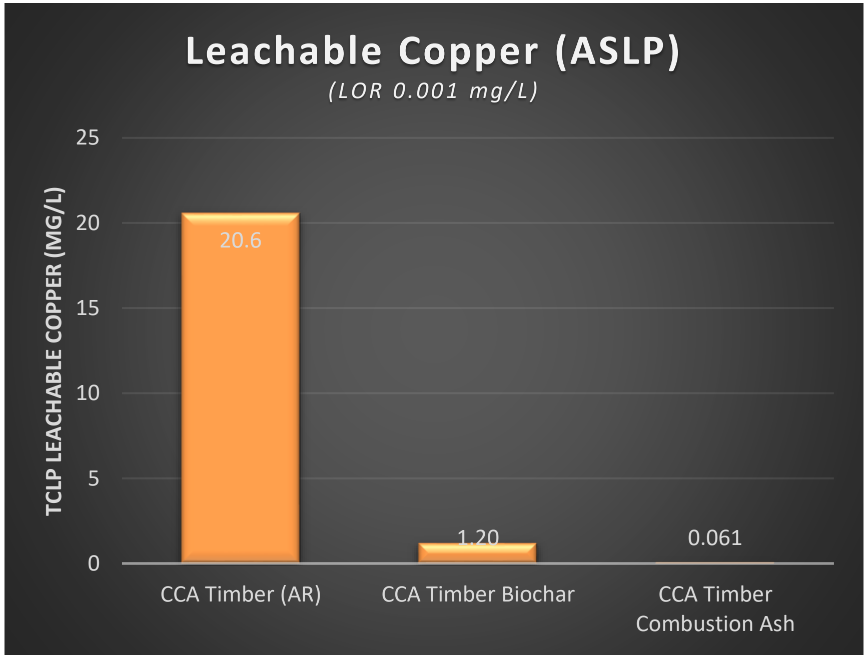
3.3 Elemental Analysis – Total and Leachable Metal Concentrations

- Total and Leachable Copper, Chromium and Arsenic results are graphed in **Figures 2-7** .
- Tabulated summaries of total metal concentrations and leachable metal concentrations are provided in **Tables 6 and 7 respectively**.
- Detailed laboratory analysis results are provided in **Appendix 1**.

It is noted that whilst being beyond the scope of work commissioned within this initial study, preliminary indication of potential leachable metals via Australian Standard Leaching Procedure (ASLP) was additionally provided to help justify further investigations, as detailed further in Sections 1.3, 4 and 5. Results are provided in Table 7.

Figures 2 and 3: Total and Leachable Copper

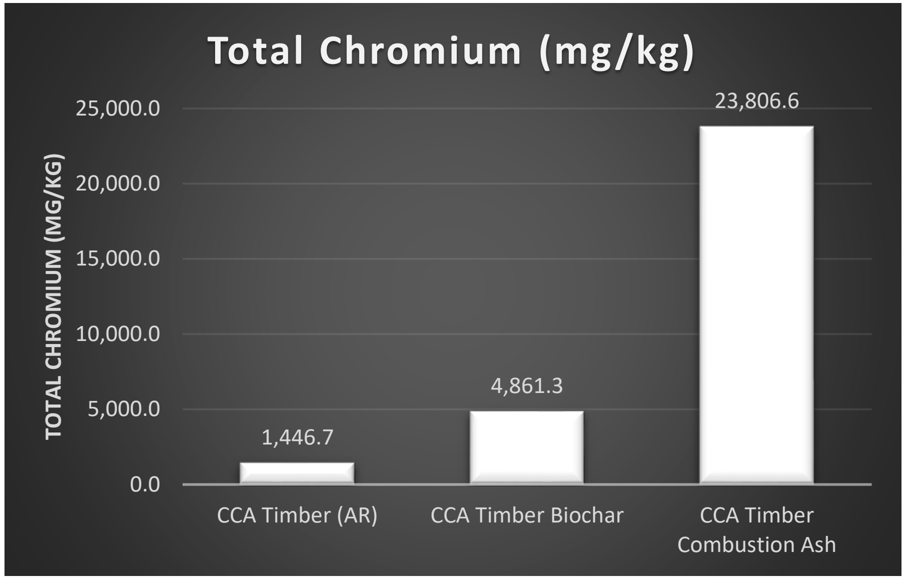


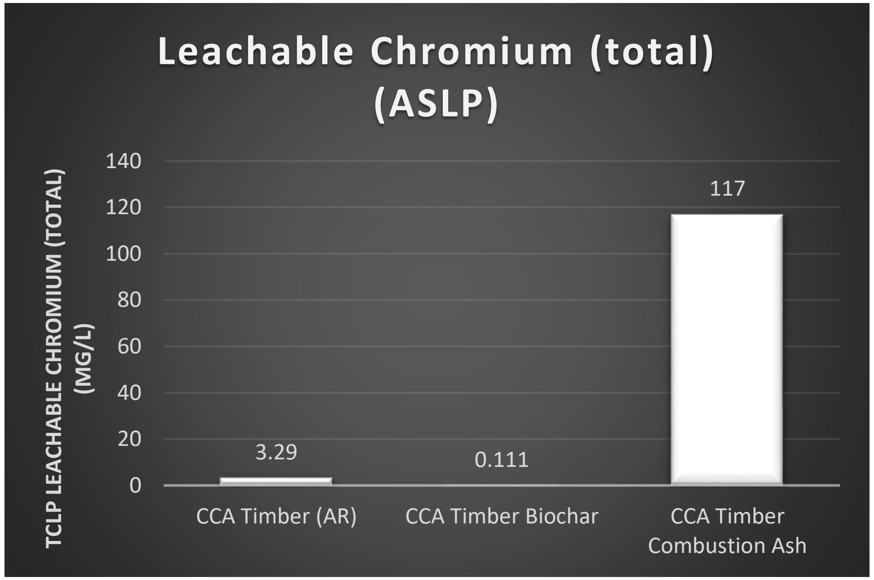


Key points of note:

- Total Copper is highly concentrated in combustion ash residue (as expected), around 10x higher than biochar, which was ~3.5x higher than treated timber feedstock.
- Leachable copper is significantly higher in the treated timber feedstock than from biochar (>17x lower), which was orders of magnitude lower again in combustion ash.

Figures 4 and 5: Total and Leachable Chromium

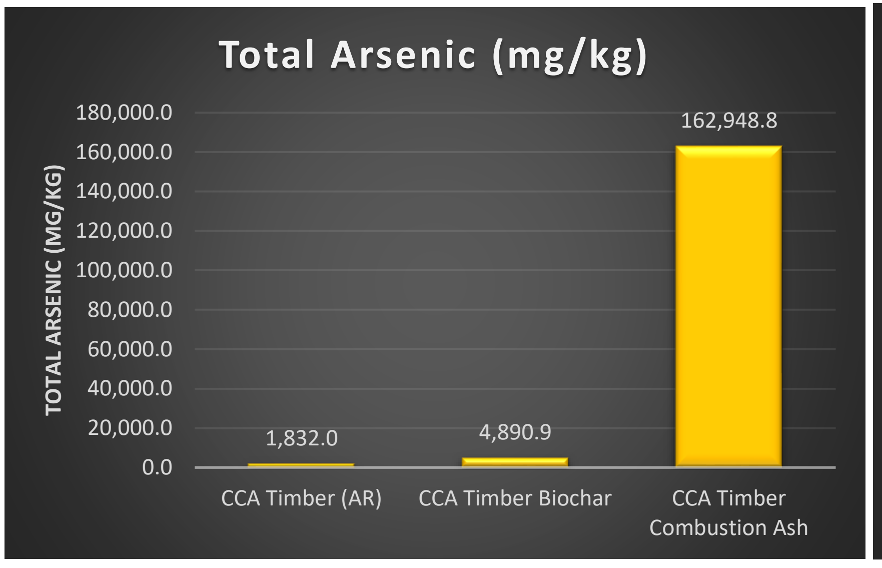


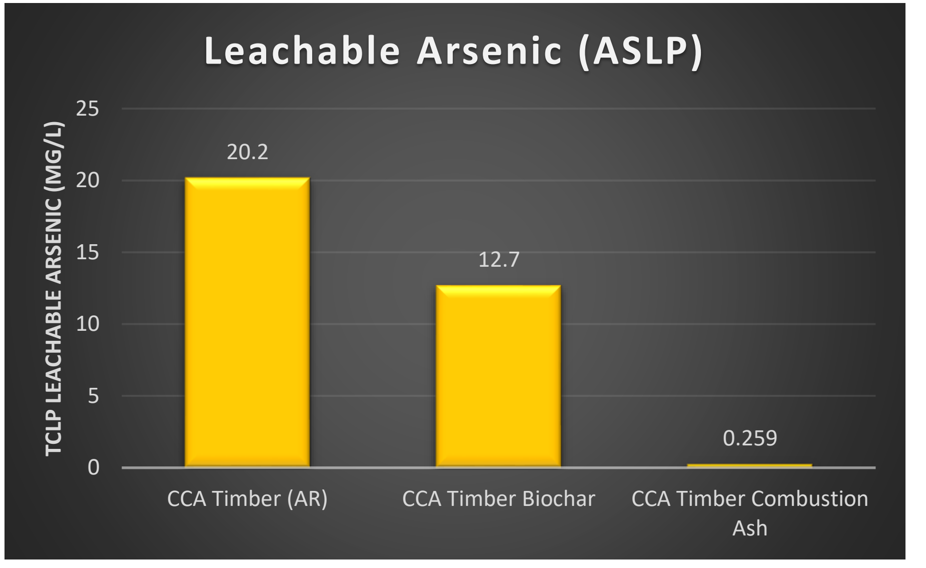


Key points of note:

- Total chromium is very highly concentrated in combustion ash (as expected), >4.5x higher than in biochar.
- Leachable chromium is low in biochar (nearly 30x lower than CCA treated timber feedstock).
- Leachable chromium is *extremely high* in combustion ash (orders of magnitude higher). This is a significant difference to Copper and Arsenic leachability. Speciation analysis would be required in future investigations to understand if this may be due to the oxidised conversion to the highly soluble and toxic form of *hexavalent* chromium (as oxides /salts of Cr(VI)).

Figures 6 and 7: Total and Leachable Chromium (correct the As value to 16,294.8 mg/kg db)





** lab result being confirmed for Total As in combustion ash.*

Key points of note:

- Total Arsenic is highly concentrated in combustion ash residue (as expected), over 30x higher than biochar, which was >2.5x greater than the treated timber feedstock.
- Arsenic in biochar and feedstock showed higher leachable characteristics than combustion ash (order of magnitude lower).
- Biochar had ~37% lower leachable Arsenic concentration than the treated timber feedstock ('ar'), reflecting the adsorption characteristics typically exhibited by biochars. Leachable arsenic was very low in combustion ash (nearly 50x lower than in the biochar).

Table 6: Laboratory Analysis Results - *Total Concentrations (Heavy Metals)*

Analyte	Units	Laboratory Analysis Results			Industry Guidelines and Regulatory Criteria:					
		CCA Timber (AR)	CCA Timber Biochar	CCA Timber Combustion Ash	ANZBIG CoP (grades range) *(V1 2021)*[1]	Potential ANZBIG Grading	EBC Criteria (Grades Range) (Dec 2024)	Potential EBC Grading	Qld EOW Code Biochar ***Unbound Applications**** *(e.g. soils*)* *EOWC010002177 (V1.01 July 2025)*	Qld EOW Code Biochar: MASCC Criteria**: (soil applications) *EOWC010002177 (V1.01 July 2025)*
Copper (total)	mg/kg	**1,197.1**	**4,201.9**	**42,191.2**	70 - 6000	**Industrial 2 only**	70 - 100	**EBC-Basic Materials Only**	**150**	100 mg/kg or background +10 (whichever greater)
Chromium (total)	mg/kg	**1,446.7**	**4,861.3**	**23,806.6**	70 - 100 (<1 for CrVI, excl IG)	**Industrial 2 only**	70 - 90	**EBC-Basic Materials Only**	**100**	100 mg/kg or background +10 (whichever greater)
Arsenic (total)	mg/kg	**1,832.0**	**4,890.9**	**162,948.8**[2]	2 - 100	**Industrial 2 only**	2-13	**EBC-Basic Materials Only**	**20**	20 mg/kg or background +3 (whichever greater)
Cadmium (total)	mg/kg	0.14	0.45	0.04	0.5 - 20	Satisfies all grades	0.7 - 1.5	Satisfies all grades	**1**	1 mg/kg
Lead (total)	mg/kg	0.4	0.9	10.7	0.2 - 300	**Soil, Industrial Grade**	10 - 120	Satisfies all grades	**150**	150 mg/kg
Nickel (total)	mg/kg	0.8	2.2	53.6	25 - 400	Satisfies all grades	25 - 50	Satisfies all grades	**60**	60 mg/kg or background +10 (whichever greater)
Zinc (total)	mg/kg	4.90	8.7	97.5	200 - 7400	Satisfies all grades	200 - 400	Satisfies all grades	**300**	200 mg/kg or background +10 (whichever greater)
Mercury (total)	mg/kg	0.13	0.02	0.01	0.02 - 10	**Soil, Industrial Grade**	0.1 - 1.0	Satisfies all grades	**1**	1 mg/kg

Notes: 1. ANZBIG Code of Practice (COP) is currently under review. Revised criteria being considered for Total Copper (30-6000), Chromium (90-100), Arsenic (13-100), Zinc (150-7400) yet TBC.
2. Lab result being confirmed for Total As in combustion ash.
* when applied to soils must also meet Maximum Allowable Soil Contaminant Concentration (MASCC)
** * The background value is that determined as the 'measured in-situ soil contaminant concentration' prior to the first biochar application

Table 7: Laboratory Analysis Results - *Leachable Heavy Metals (ASLP[1])*

Leachable Metal	Units	CCA Timber (AR)	CCA Timber Biochar	CCA Timber Combustion Ash	Qld EOW Code for Biochar TCLP[1] Limit - *Unbound Applications* *(e.g. soils*)*
Copper	mg/L	**20.6**	**1.20**	0.061	**0.2**
Chromium (total)	mg/L	**3.29**	**0.111**	**117**	**0.1**
Arsenic	mg/L	**20.2**	**12.7**	**0.259**	**0.1**
Cadmium	mg/L	0.0009	<0.0001	<0.0001	**0.01**
Lead	mg/L	0.002	<0.001	0.001	**0.0034**
Nickel	mg/L	0.007	<0.001	<0.001	**0.2**
Zinc	mg/L	1.10	0.245	0.467	**2**
Mercury	mg/L	<0.0005	<0.0001	<0.0001	**0.02**

Note: 1. Refer Section 4 and 5 for discussion of context for ASLP and TCLP leaching tests.

4. Discussion and Conclusions

Copper, Chrome and Arsenic (CCA) treated timber contains high concentrations of heavy metals (particularly CCA) which present technical and economic challenges for management via disposal or potential recovery. This preliminary study investigated the potential environmental benefits of alternative management via pyrolysis thermal treatment (conversion to biochar) over combustion/incineration. Pyrolysis to biochar was investigated for its potential to provide improved outcomes for air quality and greenhouse gas emissions and potentially usable/recoverable products including solid carbon (biochar) for industrial purposes and syngas for energy, whilst concurrently significantly reducing volumes of CCA material for transport and disposal (including if biochar was ultimately directed to disposal if required).

The results generally aligned with expectations as follows:

- **Yields:** Ash yield via combustion (by mass from feedstock) was only **1.08%** (dry basis), implying **nearly 99% was emitted to the atmosphere**. Biochar yield by mass from feedstock was **35.0%** (dry basis). This very significant difference has positive implications for biochar over combustion in terms of both air pollutants and GHG emissions (climate performance). Ash from burning CCA-treated timber has potential to be considered hazardous due to the high concentration of toxic metals.
- **Carbon Emissions/Sequestration (Climate Performance)** - Significant proportions of carbon were retained as fixed carbon in biochar (~74%) compared to combustion (0%). Combined with the difference in mass yields (above), these provide very significant

climate and air quality (particulates etc) benefits for pyrolysis to biochar over combustion to ash, as expected.

- **Total Metal Concentrations** – Combustion ash from CCA timber very significantly concentrated total metals for copper (10x higher), chrome (4.5x higher) and arsenic (30x higher) compared to biochar. The target temperature of pyrolysis (400°C) was selected to deliberately minimise the amount of arsenic sublimating and volatilising (lost to gas phase), seeking to keep it in biochar for potential future recovery. **Table 8** below provides indicative temperatures for phase transition of CCA and typical oxides. Similar results showing significantly higher concentrations in combustion ash than in biochar and treated timber feedstock were also obtained for other metals and trace elements notably including Boron, Manganese, Barium, Antinomy, Vanadium and Strontium, among others.
- **Leachable Metals:** Whilst acknowledged as preliminary results via ASLP, leachable concentrations of copper, chromium and arsenic from treated timber, biochar and ash were generally not suitable for unbound soil applications, as expected. Combustion Ash from CCA timber contained significantly higher leachable Chromium (toxic) than biochar from CCA timber (orders of magnitude higher), but was *significantly lower* for copper and arsenic.
    - High temperatures and oxidative conditions of combustion has potential to convert a portion of the trivalent Cr(III) in CCA timber feedstock into the more toxic and more soluble hexavalent form, Cr(VI). Further investigations are required to determine speciation of chromium, potentially present as soluble oxides / salts of toxic hexavalent chromium (Cr(VI)). This would further confirm a significant environmental benefit of preferential conversion to biochar over combustion ash.
    - Significantly higher temperatures during combustion alter the chemical speciation and physical encapsulation of metals such as copper and arsenic. Intense heat during combustion causes the metals to change chemical form and bind strongly within a stable, heat-resistant ash matrix. The metals can form highly insoluble compounds (e.g. calcium arsenates and copper oxides), which are very stable and difficult to leach. A significant portion of arsenic can volatilize and be released as a gas (e.g., arsenic trioxide) during high-temperature combustion, meaning less arsenic is retained in the solid ash residue to potentially leach out. At very high combustion temperatures, vitrification or sintering (agglomeration) of ash residue can also occur, physically encapsulating metal compounds preventing leaching.

- Leachable concentrations of CCA metals from biochar warrants further consideration and investigation for potential recovery as noted separately further below.
- Should *disposal* of biochar from CCA timber be considered in future, testing for both Total and Leachable concentrations using TCLP would be required to classify the waste in accordance with NSW Waste Classification Guidelines.

- **Halogens** – Chlorine results were **below detection limit** (<0.1 %) for all tests. Fluorine results were below or on detection limit (<2 mg/kg) for all tests. This bides well for thermal treatment in relation to lower potential risk of secondary formation of Dioxins and Furans and acid gases in air emissions for potential field scale trials (air pollutants of particular focus for regulators).
- **CCA biochar quality (grading)** – expectedly, biochar quality was constrained by the principle copper chrome and arsenic constituents. These typically aligned with **special-use industrial / material use classifications** under the ANZ Biochar Industry Code of Practice (**Industrial Grade 2**) and European Biochar Certificate (EBC). These are special-use classifications. Due to the concentration of potentially hazardous metals in biochars from CCA, bound applications are required. Such applications should not involve significant potential for re-exposure as air emissions in future (e.g. cutting) without appropriate controls. Other industrial uses such as reprocessing/recovery of valuable CCA metals could be considered as discussed immediately below.
- Pyrolysis was operated at 400°C, so the volatile metals substantially remained in the solid phase (biochar) except for Hg. In comparison, combustion is undertaken at 900°C, which resulted in high volatisation of metals, as expected. Of particular interest in this case is Cu, Cr and As (CCA), with high mass recovery to biochar fraction, hence low emission to the gas phase and therefore not creating another waste stream to deal with, i.e. spent scrubbing liquors. Biochars containing these metals could potentially be ideal as carbonaceous additions to lead-zinc smelts such as Glencore at Mt. Isa (QLD) or Nystar at Port Pirie (SA). Whilst only a preliminary investigation, initial results showed leachable CCA in biochar that could be further investigated for potential circular recovery (e.g. more aggressive acid leach and precipitation) for potential reuse in treating new CCA timbers.

Table 8: Temperature Data for Copper, Chromium, Arsenic, and Selected Oxides

Substance	Formula	Melting Point (°C)	Boiling Point/ Volatilization Point (°C)	Phase Transition Ranges/Notes
Copper	Cu	1084.62	~2562 - 2927	Transitions from solid to liquid at a specific point under standard pressure.
Copper(I) oxide	Cu_2O	1232 - 1235	1800 (decomposes)	Decomposes above 1800°C.
Copper(II) oxide	CuO	~1326 - 1362	~1026 (decomposes)	Decomposes at approximately 1026°C to form Cu_2O and oxygen.
Chromium	Cr	1907	2671	solid at room temperature.
Chromium(II) oxide	CrO	**~300 (decomposes)**	Not applicable	Decomposes upon heating.
Chromium(III) oxide	Cr_2O_3	2330 - 2435	2954 - 4000	A very stable, high-melting refractory material used as a green pigment. Insoluble in water and most acids.
Chromium(IV) oxide	CrO_2	**>375** (decomposes)	Not applicable	Decomposes to Cr_2O_3 at temperatures above ~375°C.
Arsenic	As	817 (at 28 atm)	614 (sublimes)	At standard atmospheric pressure, arsenic transitions directly from a solid to a gas (**sublimation**) at 614°C. The liquid phase only exists under high pressure (above 3.63 MPa).
Arsenic trioxide	As_2O_3	**312**	**465 (sublimes)**	Sublimes readily at atmospheric pressure. The liquid phase only exists under specific high-pressure conditions.

Notes:

- **Standard Pressure**: Unless otherwise noted, these values are at standard atmospheric pressure (1 atm or 101.325 kPa).
- **Volatilization**: This term describes the ease with which a substance turns into a gas. For arsenic and arsenic trioxide, this happens via sublimation at standard pressure, a direct solid-to-gas transition.
- **Decomposition**: Many metal oxides decompose into different, more stable oxides and/or release oxygen gas upon heating, rather than melting or boiling as a single compound. For this reason, their boiling points are often listed as "decomposes" or have a wide range of reported values depending on the pressure and atmosphere.

5. Recommendations

As detailed in Sections 3 and 4 above, the results of preliminary testwork undertaken at batch scale to compare pyrolysed CCA treated timber to combustion ash has provided encouraging preliminary results for pyrolysis to biochar. Based on these results, progressive further investigation is considered warranted. The following recommendations are made:

1. **"Phase 2" batch-scale testing** – the results from current investigations justify investment in expanding the scope further, potentially in a staged approach if/as necessary. This includes:
    - Detailed literature review to support development of an expanded program outlined below.
    - Develop a more comprehensive data set (expanded representative sampling and analysis), including variable processing temperatures. Potential targeting of the concentrated CCA-treated outer layers of logs versus whole log.
    - TCLP Leaching tests for metals (aggressive acid leach) – investigate potential for further leachable metals for potential processing for recovery.
        - Investigate the leachates further for potential reuse/recovery, including in industrial processes (e.g. smelters) or circular reuse in treating new CCA timbers. This includes consideration of potential pre or post production treatments of feedstock or biochar to facilitate this.
    - Further investigation of speciation in leachable chromium is recommended, as a number of oxides (and oxide salts) of toxic hexavalent chromium are highly soluble. Sodium and potassium oxide salts (soluble) should be included in such investigations.

2. **Phase 3 – Field-scale testing (Continuous plant)**

2.1 This would further assess/validate the **syngas generation** estimates obtained from current preliminary tests. This can also be staged with initial indicative high level analysis ahead of detailed testing (more expensive) as outlined below.

2.2 Progressive testing from preliminary continuous run (proximate and ultimate analysis) toward detailed trials (e.g. two weeks) for full mass and energy balance with comprehensive analysis. Data from detailed trials can inform feasibility studies and data required for impact assessments/approvals for commercial scale deployment.

2.3 Note: It is assumed next phase testing at field scale would utilise the same technology used for the current preliminary tests. Any field testing undertaken should consider relevant approvals and appropriate air emissions controls for the required tests.

As outlined in **Section 2** (Background), the following aspects can also be relevant for treated timber in addition to focus elements Copper, Chrome and Arsenic (CCA). These were beyond the scope of current preliminary investigations and are recommended for consideration within the scope of future investigations (noting these could also be tested at bench scale prior to field scale if required):

- **Other specific copper compounds** (e.g. copper carbonate hydroxide)
- **Boron** compounds
- **Sodium nitrite**
- **Fungicides** (e.g. Tebuconazole) **and other organic/organo-chlorine residues** (e.g. herbicides, pesticides etc). These may contain halogens such as Chlorine which have potential to form problematic organic compounds when combusted, such as dioxins and furans.

APPENDICES

Appendix 1: Laboratory Analysis Reports (Certificates of Analyses (COA))

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Boron	[illegible]	[illegible]	[illegible]
Cadmium	[illegible]	[illegible]	[illegible]
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Selenium	[illegible]	[illegible]	[illegible]
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Nickel	[illegible]	[illegible]	[illegible]
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Ash Analysis (XRF)

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Laboratory Analysis

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Chlorine	□0□01	□	□ad□

Standards/Method List

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CERTIFICATE OF ANALYSIS

Work Order	: **EB2525653**	Page	: 1 of 5
Client	: **ACIRL PTY LTD**	Laboratory	: Environmental Division Brisbane
Contact	: TOM FINN	Contact	: Kelly Schafer
Address	: 7 Brisbane Road 4303	Address	: 2 Byth Street Stafford QLD Australia 4053
Telephone	: ----	Telephone	: +61 7 4978 7944
Project	: TQ25003070	Date Samples Received	: 24-Jul-2025 11:30
Order number	: AC42338	Date Analysis Commenced	: 25-Jul-2025
C-O-C number	: ----	Issue Date	: 30-Jul-2025 15:59
Sampler	: ----		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 3		
No. of samples analysed	: 3		

Accreditation No. 825
Accredited for compliance with
ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Beatriz Llarinas	Senior Chemist	Brisbane Inorganics, Stafford, QLD
Beatriz Llarinas	Senior Chemist	Brisbane Soil Preparation, Stafford, QLD

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contract for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EG035W (Water Leachable Mercury by FIMS): Limit of reporting raised for 25/018 CCA Timber 'ar' Head Sample 12 June 25 (EB2525653-001) due to matrix interference.

Analytical Results

Sub-Matrix: **ASLP LEACHATE**
(Matrix: **WATER**)

			Sample ID	25/018 CCA Timber 'ar' Head Sample 12 June 25 TQ25003070#001	25/019 CCA Timber Biochar 400°C 15 June 25 TQ25003070#002	25/020 CCA Timber Ash 14 June 25 TQ25003070#003	----	----
			Sampling date / time	12-Jun-2025 00:00	15-Jun-2025 00:00	14-Jun-2025 00:00	----	----
Compound	CAS Number	LOR	Unit	EB2525653-001	EB2525653-002	EB2525653-003	--------	--------
				Result	Result	Result	----	----
EG020W: Water Leachable Metals by ICP-MS								
Arsenic	7440-38-2	0.001	mg/L	**20.2**	**12.7**	**0.259**	----	----
Cadmium	7440-43-9	0.0001	mg/L	**0.0009**	<0.0001	<0.0001	----	----
Chromium	7440-47-3	0.001	mg/L	**3.29**	**0.111**	**117**	----	----
Copper	7440-50-8	0.001	mg/L	**20.6**	**1.20**	**0.061**	----	----
Lead	7439-92-1	0.001	mg/L	**0.002**	<0.001	**0.001**	----	----
Nickel	7440-02-0	0.001	mg/L	**0.007**	<0.001	<0.001	----	----
Zinc	7440-66-6	0.005	mg/L	**1.10**	**0.245**	**0.467**	----	----
EG035W: Water Leachable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0005	<0.0001	<0.0001	----	----

Analytical Results

Sub-Matrix: PULP
(Matrix: SOIL)

			Sample ID	25/019 CCA Timber Biochar 400°C 15 June 25 TQ25003070#002	25/020 CCA Timber Ash 14 June 25 TQ25003070#003	----	----	----
			Sampling date / time	15-Jun-2025 00:00	14-Jun-2025 00:00	----	----	----
Compound	CAS Number	LOR	Unit	EB2525653-002	EB2525653-003	--------	--------	--------
				Result	Result	----	----	----
EN60: ASLP Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	**7.3**	**12.3**	----	----	----

Analytical Results

Sub-Matrix: WOOD (Matrix: SOIL)			Sample ID	25/018 CCA Timber 'ar' Head Sample 12 June 25 TQ25003070#001	----	----	----	----
			Sampling date / time	12-Jun-2025 00:00	----	----	----	----
Compound	CAS Number	LOR	Unit	EB2525653-001	--------	--------	--------	--------
				Result	----	----	----	----
EN60: ASLP Leaching Procedure - Inorganics/Non-Volatile Organics (Glass Vessel)								
Final pH	----	0.1	pH Unit	**3.9**	----	----	----	----

Appendix 2: Mass Balance Details

SEATA

CCA Timber Testwork

Mass Balance

Pyrolysis

Rev 3			*25/018*	*25/019*	*(calc.)*
20-Nov-25			**CCA** Timber IN (s)	**Biochar** OUT (s)	**Raw Syngas** OUT (g)
Overall Mass Recoveries		% ad	100.0%	35.0%	65.0%
		% db	100.0%	36.1%	63.9%
(Organic components)	Moisture	mass %	100.00	15.00	85.00
	Carbon	mass %	100.00	61.36	38.64
	Hydrogen	mass %	100.00	19.93	80.07
	Nitrogen	mass %	100.00	78.23	21.77
	Sulfur	mass %	100.00	1.59	98.41
	Oxygen	mass %	100.00	10.82	89.18
(Inorganic components	Copper	mass %	100.00	100.00	0.00
	Chromium	mass %	100.00	100.00	0.00
	Arsenic	mass %	100.00	97.46	2.54
	Cadmium	mass %	100.00	100.00	0.00
	Lead	mass %	100.00	82.14	17.86
	Nickel	mass %	100.00	100.00	0.00
	Zinc	mass %	100.00	64.82	35.18
	Mercury	mass %	100.00	5.62	94.38
	Fluorine	mass %	100.00	36.51	63.49
	Boron	mass %	100.00	100.00	0.00
	Selenium	mass %	100.00	100.00	0.00
	Molybdenum	mass %	100.00	36.51	63.49
	Manganese	mass %	100.00	100.00	0.00
	Barium	mass %	100.00	83.44	16.56
	Beryllium	mass %	100.00	36.51	63.49
	Cobalt	mass %	100.00	36.51	63.49
	Lithium	mass %	100.00	36.51	63.49
	Antimony	mass %	100.00	100.00	0.00
	Tin	mass %	100.00	73.01	26.99
	Uranium	mass %	100.00	36.51	63.49
	Vanadium	mass %	100.00	80.83	19.17
	Thorium	mass %	100.00	36.51	63.49
	Thallium	mass %	100.00	36.51	63.49
	Strontium	mass %	100.00	100.00	0.00
	Na2O	mass %	100.00	100.00	0.00
	P2O5	mass %	100.00	100.00	0.00
	SiO2	mass %	100.00	100.00	0.00
	Al2O3	mass %	100.00	100.00	0.00
	Fe2O3	mass %	100.00	100.00	0.00
	TiO2	mass %	100.00	100.00	0.00
	CaO	mass %	100.00	100.00	0.00
	MgO	mass %	100.00	100.00	0.00
	K2O	mass %	100.00	100.00	0.00
	Mn304	mass %	100.00	100.00	0.00
	SO3	mass %	100.00	100.00	0.00

Combustion

Rev 3			*25/018*	*25/020*	*(calc.)*
20-Nov-25			**CCA** Timber IN (s)	**Ash** OUT (s)	**Combustion** Off-gas OUT (g)
Overall Mass Recoveries		% ad	100.0%	1.1%	98.9%
		% db	100.0%	1.2%	98.8%
(Organic components)	Moisture	mass %	100.00	0.00	100.00
	Carbon	mass %	100.00	0.00	100.00
	Hydrogen	mass %	100.00	0.00	100.00
	Nitrogen	mass %	100.00	0.00	100.00
	Sulfur	mass %	100.00	0.00	100.00
	Oxygen	mass %	100.00	0.00	100.00
(Inorganic component	Copper	mass %	100.00	42.60	57.40
	Chromium	mass %	100.00	19.89	80.11
	Arsenic	mass %	100.00	10.75	89.25
	Cadmium	mass %	100.00	0.35	99.65
	Lead	mass %	100.00	32.34	67.66
	Nickel	mass %	100.00	80.99	19.01
	Zinc	mass %	100.00	24.05	75.95
	Mercury	mass %	100.00	0.09	99.91
	Fluorine	mass %	100.00	1.21	98.79
	Boron	mass %	100.00	99.73	0.27
	Selenium	mass %	100.00	26.59	73.41
	Molybdenum	mass %	100.00	66.49	33.51
	Manganese	mass %	100.00	66.33	33.67
	Barium	mass %	100.00	19.04	80.96
	Beryllium	mass %	100.00	2.42	97.58
	Cobalt	mass %	100.00	18.13	81.87
	Lithium	mass %	100.00	13.30	86.70
	Antimony	mass %	100.00	100.00	0.00
	Tin	mass %	100.00	2.42	97.58
	Uranium	mass %	100.00	2.42	97.58
	Vanadium	mass %	100.00	60.61	39.39
	Thorium	mass %	100.00	0.00	100.00
	Thallium	mass %	100.00	0.00	100.00
	Strontium	mass %	100.00	38.65	61.35
	Na2O	mass %	100.00	100.00	0.00
	P2O5	mass %	100.00	100.00	0.00
	SiO2	mass %	100.00	100.00	0.00
	Al2O3	mass %	100.00	100.00	0.00
	Fe2O3	mass %	100.00	100.00	0.00
	TiO2	mass %	100.00	100.00	0.00
	CaO	mass %	100.00	100.00	0.00
	MgO	mass %	100.00	100.00	0.00
	K2O	mass %	100.00	30.00	70.00
	Mn304	mass %	100.00	100.00	0.00
	SO3	mass %	100.00	15.00	85.00