Australia Samples System Operation Report Phase 2

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Abbreviation

ABBREVIATION	DEFINITIONS
Al	Aluminium
As	Arsenic
Ba	Barium
BRE	Bluefield Renewable Energy Pte Ltd
C	Carbon
Ca	Calcium
Cd	Cadmium
Co	Cobalt
CP	Cotton Pellets
Cr	Chromium
Cu	Copper
EBC	European Biochar Certificate
EPA	Australia Environmental Protection Agency
Fe	Iron
H	Hydrogen
H/C_{org}	Molar Ratio of Hydrogen over Organic Carbon
Hg	Mercury
HHV	High Heating Value
K	Potassium
LPG	Liquefied Petroleum Gas
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
NEA	National Environment Agency Singapore
Ni	Nickel
O	Oxygen
O/C_{org}	Molar Ratio of Oxygen over Organic Carbon
Pb	Lead
S	Sulphur
Sb	Antimony
Se	Selenium
Sn	Tin
TCLP	Toxicity Characteristic Leaching Procedure
Ti	Titanium
V	Vanadium
Zn	Zinc

Table of Content

1 Executive Summary

The Phase 2 test runs using almond and cotton feedstock in BRE's system have provided significant insights into the system's performance, efficiency and areas for optimization. Both biochar samples were sent to a third-party laboratory for testing to evaluate the biochar properties. It was observed that the elemental content for both almond and cotton biochar samples fall within the EBC's standard. Furthermore, the TCLP tests for both almond and cotton biochar samples also meet the EBC requirements. However, the cotton pellets biochar had a Oxygen / Organic Carbon molar ratio of more than 0.4 which fails the EBC requirements while almond hulls pellet biochar complies with the EBC requirements for both Oxygen / Organic Carbon and Hydrogen / Organic Carbon molar ratio.

For the almond feedstock, the flowmeter data recorded during steady-state syngas production revealed LHV values ranging from approximately 6.4 MJ/m^3 to 7.3 MJ/m^3, with an average of 6.85 MJ/m^3. This indicates a high energy content for the almond feedstock. The syngas flowrate directed to the burner ranged from 40 to 60 m^3/hr, with no excess syngas introduced to the flare.

In contrast, the cotton feedstock test runs showed LHV values ranging from 4.5 MJ/m^3 to 6.9 MJ/m^3, peaking around 6.8 MJ/m^3 and averaging approximately 5.9 MJ/m^3. While slightly lower in energy content compared to almond feedstock, it can provide excess syngas production. The total syngas flowrate across cotton test runs varied between 75 to 85 m^3/hr, averaging 80.85 m^3/hr, with syngas directed to the burner remaining steady between 55 to 65 m^3/hr, averaging 59.81 m^3/hr. This implies that there is an excess syngas produced averaging 21.04 m^3/hr. Hence, there is a potential to utilize the excess syngas to generate heat for external usage.

Wood chip syngas provides the highest power output of 134.4 kW, attributed to its higher LHV of 12 MJ/m^3 and flow rate of 40 m^3/hr. Moreover, cotton pellet syngas generates a moderate power output of 34.692 kW, due to its lower LHV of 5.9 MJ/m^3. Although propane gas boasts the highest LHV of 50.3 MJ/m^3, the required flow rate to operate the baler machine is consider low at 1.1 m^3/hr, resulting in a lower power output of 15.492 kW, which is less than that of cotton pellet syngas. Utilizing the excess syngas from cotton pellets can potentially replace some or all of the propane gas, leading to reduced operating costs for the baler machine.

Tests were performed on the flue gas emissions resulting from the combustion of the syngas generated from both feedstocks to verify their compliance with the environmental standards set by Australia's EPA. As shown in the Appendix, the findings indicate that the levels of pollutants released into the atmosphere from BRE's system are within the acceptable limits specified by the EPA. This ensures that the operations are environmentally compliant and contribute positively to air quality standards as mandated by Australian regulatory authorities.

2 Objective

Phase 2 of the project will involve the evaluation and testing of cotton and almond waste feedstock within the BRE's operating system. This phase is important for assessing the operational efficiency, compatibility and overall performance of these specific feedstocks in the system.

Figure 2-1: Almond and Cotton Feedstock

During this phase 2, a series of test runs were conducted to analyze various parameters including the by-products output, combustion efficiency and emission levels.

This report provides a comprehensive overview of the operation summary for both feedstocks in BRE's system and the test analysis for the outputs.

3 Results and Discussion

3.1 Operation Summary (Almond)

Table 3-1 presents an operational summary for all test runs using almond feedstock. It includes key parameters such as feeding rate, moisture content, biochar yield, and temperature. This summary serves as a benchmark for comparing the efficiency and effectiveness of different feedstocks in similar operational settings.

The average feeding rate for all runs is recorded to be 236.15 kg/hr. This parameter represents the average rate at which almond feedstock is introduced into the system per hour. A higher feeding rate indicates the system's capacity to handle substantial input, which can influence the overall efficiency and output. Furthermore, the average moisture for total feed is 10%, which is considered low as the feedstock are pre-processed and pelletized. Moisture content is a crucial factor as it affects the reactor temperature and the quality of the syngas produced [8].

Moreover, the average biochar production yield is approximately 23.31%, which is considered high in yield for fast pyrolysis [7]. This parameter shows the percentage of the feedstock that is converted into this valuable by-product, biochar. The process temperature range is maintained between 650-750°C. Maintaining process temperatures within this range is essential for optimal pyrolysis, ensuring efficient breakdown of feedstock into syngas and biochar.

Additionally, the LPG usage for all runs were averaged to be 10.573 m^3. LPG is used as a supplementary fuel to heat up the reactor and maintain the required temperatures. During the process, syngas produced will be recycled back into the burner for combustion to replace the LPG completely. Hence, the main operating cost of BRE's system which is LPG usage can be reduced.

Table 3-1: Operation Summary for All Almond Runs

	Units	Value
Average Feeding Rate	Kg/hr	236.15
Average Moisture for Total Feed	%	10
Biochar Production Yield	%	23.31
Process Temperature Range	°C	650-750
LPG Usage	m^3	10.573

Figure 3-1: Almond Biochar from BRE's System

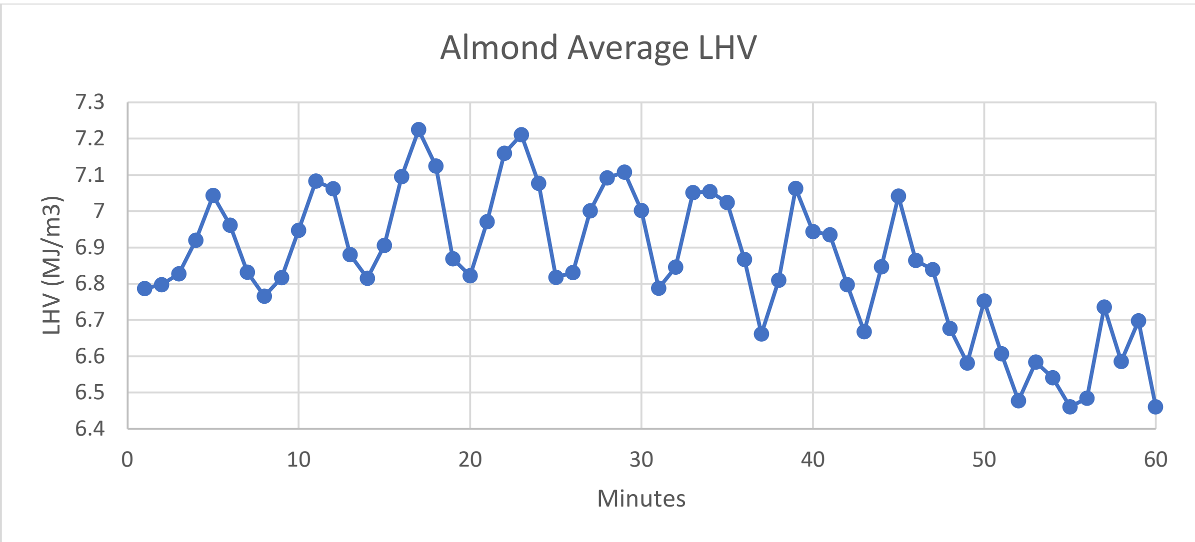

Figure 3-2: Average LHV for Almond Syngas Production

The flowmeter data was recorded when the syngas production is in steady state for all almond test runs. Figure 3-2 illustrates the average Lower Heating Value (LHV) in megajoules per cubic meter (MJ/m^3) over a 60-minute steady state period. The LHV, which indicates the energy content of the almond feedstock when combusted (excluding the latent heat of vaporization of water) [6], fluctuates between approximately 6.4 MJ/m^3 and 7.3 MJ/m^3. Throughout the steady-state period for all almond test runs, the LHV values exhibit an oscillatory pattern, maintaining a relatively constant range. This consistent behaviour suggests stable energy output despite the inherent fluctuations.

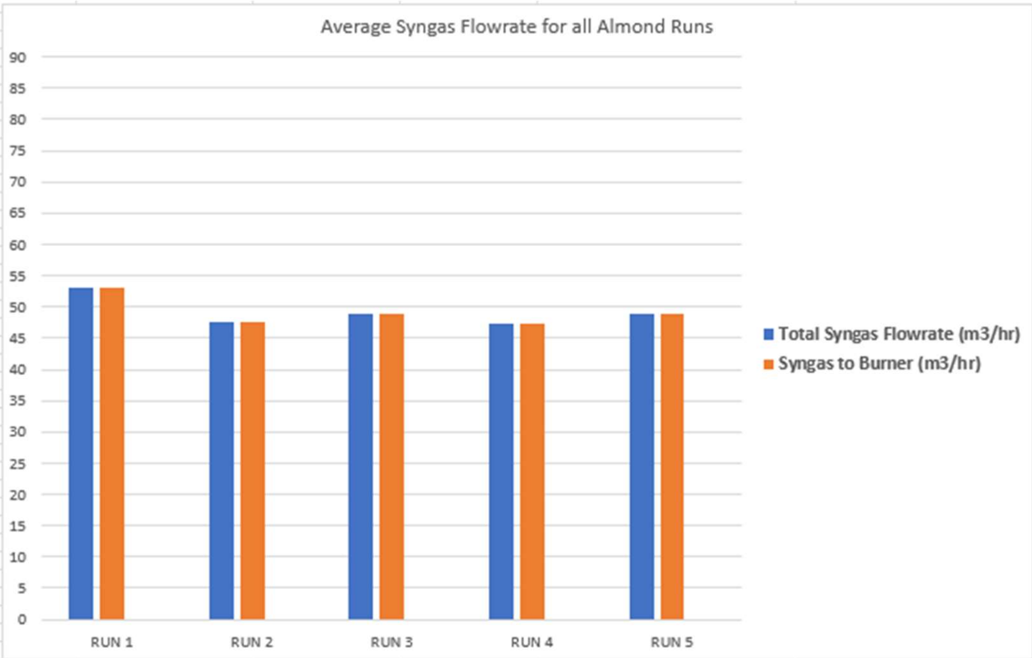

Figure 3-3: Average Almond Syngas Production and Flowrate

Figure 3-3 titled "Average Syngas Flowrate for all Almond Runs" presents the average syngas flowrate for five different runs using almond feedstock. It includes two key metrics for each run:

- Total Syngas Flowrate (m^3/hr): Represented by blue bars
- Syngas Flowrate to Burner (m^3/hr): Represented by orange bars

The graph displays consistent syngas flowrates across all five runs, with total flowrates ranging from approximately 45 m^3/hr to 55 m^3/hr. This consistency indicates a robust syngas production capacity throughout the runs. In each case, all syngas produced was directed to the burner to maintain reactor temperature. This approach highlights the system's ability to effectively replace LPG with syngas, thereby reducing reliance on external fuel sources and contributing to cost savings. Overall, the average syngas flowrate directed to the burner ensures operational efficiency with no excess syngas produced.

3.2 Operation Summary (Cotton)

Table 3-2 provides an operational summary for all test runs utilizing cotton feedstock, detailing key parameters such as feeding rate, moisture content, biochar yield, temperature ranges and LPG usage. This summary acts as a benchmark for evaluating the efficiency and effectiveness of various feedstocks under similar operational conditions.

The average feeding rate for all runs is recorded at 184.39 kg/hr, reflecting the system's capacity to process substantial input, thereby influencing overall efficiency and output. There is more room to increase the throughput with more recipe development.

The average moisture content of the total feed for all runs is 10%, which is relatively low due to pre-processing and pelletisation of the feedstock. Moisture content is a critical factor as it impacts the reactor temperature and the quality of the generated syngas [8].

Additionally, the average biochar production yield is approximately 21.03%, a high yield for fast pyrolysis processes [7]. This yield indicates the percentage of feedstock converted into biochar, our main by-product. The process temperature range is maintained between 650-750°C.These temperature ranges are essential for optimal pyrolysis, ensuring efficient conversion of feedstock into syngas and biochar.

LPG usage for all runs averages 9.951 m^3, serving as supplementary fuel to supply heat to the reactor and maintain the required temperatures. During the process, the generated syngas is recycled back into the burner for combustion, eventually replacing LPG entirely. This recycling helps to reduce the main operating cost associated with LPG usage in BRE's system.

Table 3-2: Operation Summary

	Units	Value
Average Feeding Rate	Kg/hr	184.39
Average Moisture for Total Feed	%	10
Biochar Production Yield	%	21.03
Process Temperature Range	℃	650-750
LPG Usage	m^3	9.951

Figure 3-4: Cotton Biochar from BRE's System

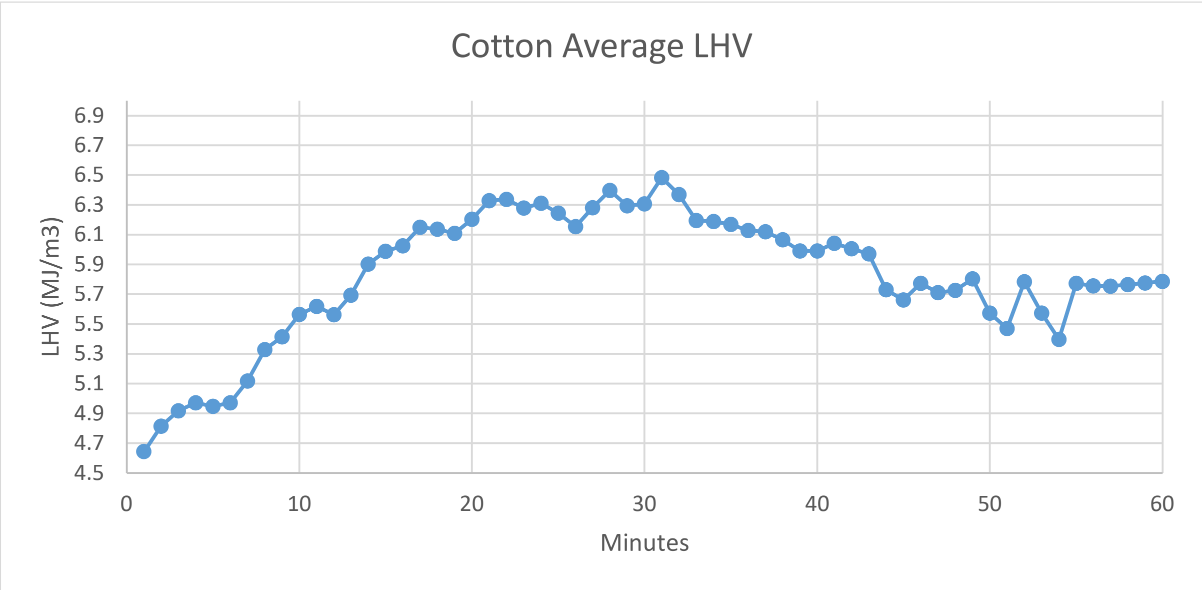

Figure 3-5: Average LHV for Cotton Syngas Production

The flowmeter data was recorded when the syngas production is in steady state across all cotton test runs. Figure 3-5 above presents the Lower Heating Value (LHV) of cotton feedstock over a 60-minute steady state period, measured in megajoules per cubic meter (MJ/m^3). The LHV values range from 4.5 MJ/m^3 to 6.9 MJ/m^3 during the steady state period for all runs. It can be seen that the LHV value peaks and stabilizes around 6.8 MJ/m^3. Overall, the cotton feedstock shows promising ability to maintain a high and steady energy output which is beneficial for continuous energy production.

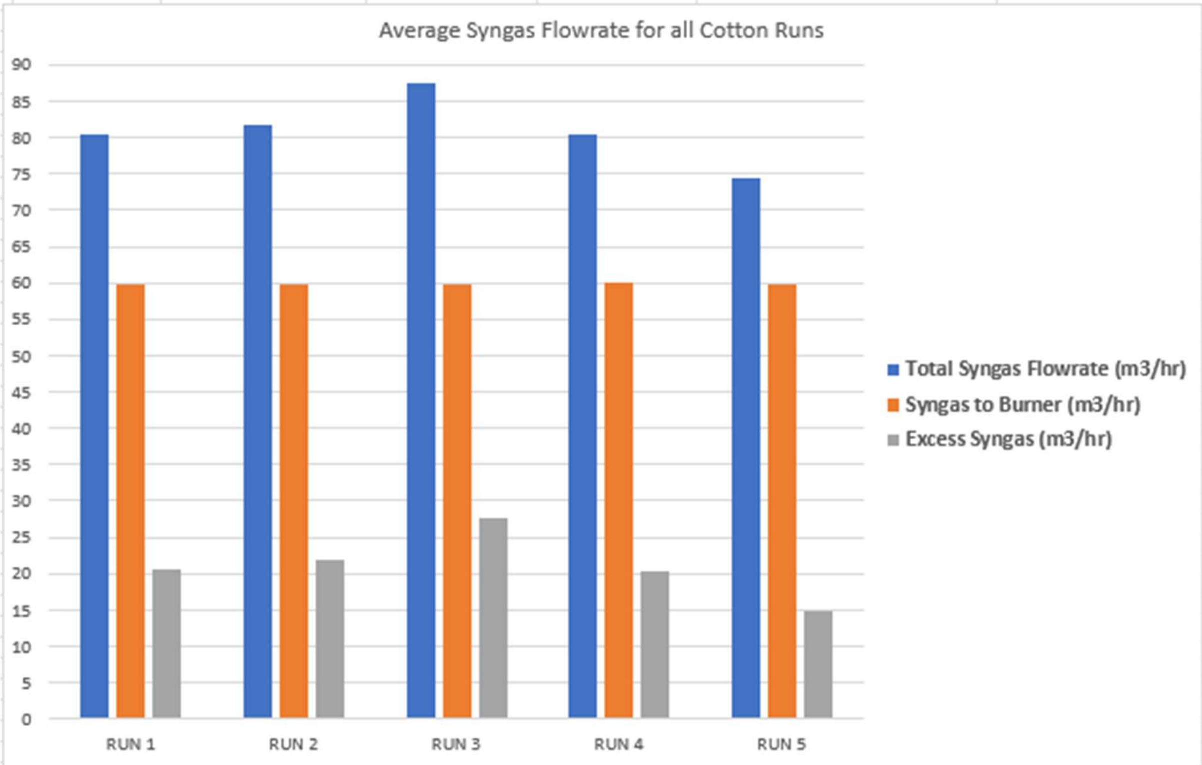

Figure 3-6: Average Cotton Syngas Production and Flowrate

Figure 3-6 titled "Average Syngas Flowrate for all Cotton Runs" provides a visual representation of the average syngas flowrates across five different test runs (RUN 1 to RUN 5). The data is broken down into three categories for each run:

- Total Syngas Flowrate (m^3/hr): Represented by blue bars
- Syngas Flowrate to Burner (m^3/hr): Represented by orange bars
- Excess Syngas (m^3/hr): Represented by gray bars

The total syngas flowrate remains relatively high across all runs with values ranging from approximately 75 to 85 m^3/hr, averaging around 80.85 m^3/hr. This indicates a robust production capacity of syngas during the runs. Furthermore, the syngas directed to the burner is fairly consistent across all runs, ranging from approximately 55 to 65 m^3/hr, with an average of 59.81 m^3/hr. The syngas directed to the burner reflects the system's capability to replace LPG with syngas effectively. Hence, dependency on external fuel sources can be reduced and contributes to cost saving. On the other hand, excess syngas which currently is directed to the flare ranges from 14 to 27 m^3/hr, giving an average flowrate of 21.04 m^3/hr. This highlights the potential for optimizing syngas utilization or integrating additional syngas consuming processes. In short, approximately 74.27% of the average syngas flowrate is directed to the burner, ensuring operational efficiency, while the remaining 25.73% can be utilized in other syngas consuming equipment in the future.

3.3 Syngas LHV and Syngas Flowrate for Cotton and Almond Feedstock

Based on the findings above, it was observed that syngas derived from almond pellets exhibits a higher LHV of approximately 6.85 MJ/m^3 compared to syngas from cotton pellets, which has an LHV of around 5.9 MJ/m^3. From the Phase 1 report, the HHV measurements for almond and cotton pellets were recorded as 18.77 kJ/g and 16.52 kJ/g respectively. HHV represents the total energy released upon complete combustion of the feedstock, including the latent heat of vaporization of water in the combustion products [6]. Therefore, a higher HHV indicates a greater energy content per unit mass of the feedstock.

With similar moisture content in both feedstocks, the higher HHV of almond pellets shows that they possess more energy per unit mass compared to cotton pellets [14]. This directly influences the energy content of the syngas produced during the pyrolysis process. Despite these energy differences, it was noted that cotton pellet feedstock generated excess syngas, whereas almond pellet feedstock did not produce surplus syngas.

The flow rate of syngas, which denotes the volume of syngas produced per unit of time, is influenced by the volatile matter content in the feedstock. Variations in volatile matter, attributable to the distinct chemical compositions and properties of different feedstocks, lead to varying amounts of syngas produced [13]. This aligns with the third-party laboratory results in Table 3-3, indicating a higher percentage of syngas produced from cotton pellets compared to almond pellets.

In summary, syngas LHV and syngas flowrate do not have a straightforward correlation. The LHV of syngas refers to the amount of energy released per unit volume of the gas when it is combusted (quality of syngas) while the flowrate of syngas refers to the volume of syngas produced per unit per time (quantity of syngas). Therefore, optimizing the production process aims to achieve a balance where both the flowrate and LHV are at desirable levels to meet energy requirements.

Table 3-3: Third-Party Laboratory Results

Sample		Cotton Pellet (%)	Almond Hulls Pellet (%)
Char	Mean	26.4	25.7
	Standard Deviation	0.3	0.8
Oil	Mean	34.8	37.1
	Standard Deviation	3.5	1.8
Gas	Mean	38.8	37.2
	Standard Deviation	3.2	2.6

3.4 Comparison for Power Generated from Different Fuel Source

To contrast the current surplus of cotton syngas, wood chip and propane gas were introduced for this section. Calculations were performed to compare the power generation capabilities of cotton syngas, wood chip syngas and propane gas. The analysis focused on computing the usable energy and resultant power output for each fuel source. Calculations were conducted and shown in the Appendix 2 section. Results were tabulated and are presented below.

Table 3-4 compares the power generation capabilities of three different fuel sources: cotton pellet syngas, wood chip syngas and propane gas. It presents their LHV values, syngas/fuel flow rate, and resulting power output.

Wood chip syngas offers the highest power output due to a combination of higher LHV and flowrate. Furthermore, cotton pellet syngas produces a moderate power output due to the combination of lower LHV. While propane gas has the highest LHV, its low required flowrate to operate the baler machine results in a lower power output, lower than cotton pellet syngas. By using excess syngas from cotton pellets, it is possible to replace some or all of the propane gas, thereby reducing the operating costs of the baler machine. However, for existing baler machines, conversion kits may be needed to switch from propane to syngas. These kits can include modifications to the fuel injection system, ignition system and exhaust handling.

Table 3-4: Results and Calculations for Power Output from Different Fuel Source

Fuel Source	Cotton Pellet	Wood Chip	Propane [17]
LHV value (MJ/m^3)	5.9	12	50.3
Syngas/Fuel Flowrate (m^3/hr)	21	40	1.1*
Power Output (kW)	34.692	134.4	15.49

*Fuel Flowrate Calculations were shown in the Appendix 2 section

3.5 Biochar Output

Comparing both cotton pellet biochar and almond hulls pellet biochar, cotton pellet biochar fails to meet EBC requirement for the Oxygen / Organic Carbon molar ratio which needs to be less than 0.4. As shown in Table 3-5 and 3-6, this is due to the lower total carbon content in the cotton pellet samples, resulting in low total organic carbon. Based on Equation 1 and 2 [4], with the decreased total organic carbon, the Oxygen / Organic Carbon molar ratio will be increased. However, the EBC would carry out a plausibility check and grant an appropriate exemption, provided that the product quality and environmental protection are guaranteed [9]. On the other hand, both biochar samples comply within the EBC requirement for the molar Hydrogen / Organic Carbon ratio which needs to be less than 0.4. This molar ratio is an indicator of the degree of carbonisation and is indispensable for the determination of the C-sink value [9].

In the Phase 1 report, the Oxygen / Organic molar ratio for cotton pellet biochar was recorded at 0.62 with the process temperature around 600°C. However, in the Phase 2 report, this ratio decreased to 0.57 as the process temperature increased to between 650°C and 750°C. This data indicates that higher process temperatures result in a lower Oxygen / Organic molar ratio in cotton pellet biochar. The reduction from 0.62 to 0.57 suggests improved biochar quality at elevated temperatures, as lower oxygen content typically correlates with higher stability and better carbon retention in the biochar [9].

$$Total\ Organic\ Carbon\ \%\ (TOC) = Total\ Carbon\ Content\ \%\ (TC) - Total\ Inorganic\ Carbon\ \%\ (TIC) \qquad (Eq1)$$

$$\frac{Oxygen}{C_{org}} = \frac{Oxygen}{\frac{TOC}{(TC \times C)}} \qquad (Eq2)$$

Almond biochar samples are strong alkali base, given their high pH level of more than 13 while cotton biochar samples have pH level of 8-9. In Phase 1 report, the pH of the cotton pellet biochar is around 13. However, the pH of biochar in this report was recorded to be around 8.5. Rehrah et al. (2014) showed that biochar derived from cotton gin exhibited the highest pH values, ranging from 8.2 to 9.8 [12]. The alkalinity of the biochar in this study can be attributed to the deprotonation of binding sites as pyrolysis proceeds, resulting in a high pH in the biochar samples. Furthermore, the pH of biochar may be influenced by the chemical properties of the functional groups present on its surface, which are inherited from the parent biomass [11]. Moving on, biochar with pH value of more than 12.5 makes it a corrosive and hazardous base substance, which will result in human or environmental health problems [10].

Table 3-5: Properties of Pelletised Biochar

Parameters	Cotton Pellet Biochar	Almond Hulls Pellet Biochar
Ash Content (%)	53.26	50.17
Bulk Density (kg/m^3)	369.55	296.5
Higher Heating Value (kJ/g)	20.59	26.12
Ultimate Analysis (Mass %)		
N	1.99	0.9
C	54.86	70.95
H	1.53	2.08
S	0.19	0.09
O	41.43	25.98
Ultimate Analysis (Molar %)		
N	1.610	0.665
C	51.77	61.14
H	17.21	21.36
S	0.07	0.03
O	29.35	16.81
O/C_{org}	0.57	0.28
H/C_{org}	0.34	0.35
Electrical Conductivity (µS/cm)	2229	13950
pH	8.67	13.66

Table 3-6: Carbon Content for Both Biochar Samples

Sample	Cotton Pellet Biochar	Almond Pellet Biochar
Total Organic Carbon (TOC) (%)	64.25	75.00
Total Carbon (TC) (%)	64.78	75.30
Total Inorganic Carbon (TIC) (%)	0.5252	0.2985

Based on Table 3-7, the elemental content of both biochar samples falls within the EBC limits which are highlighted in pink. Both pelletised biochar samples share similar heavy metal content and attained the highest grade of EBC standard ('Feed' grade), which means that biochar produced can be used in industrial application.

Table 3-7: Total Element Content for Both Biochar

Element	EBC standards					Cotton Pellet Biochar (650 – 750)°C (mg/kg)	Almond Hulls Pellet Biochar (650 – 750)°C (mg/kg)
	Feed	Agro Organic	Agro	Urban	Consumer Materials		
Al	-	-	-	-	-	3.741±0.4846	1.632±0.0531
As	2	13	13	13	13	0.0005±0.0001	0.0003±0
Ba	-	-	-	-	-	0.1223±0.0035	0.0266±0.0019
Ca	-	-	-	-	-	50.6988±5.6589	9.68±0.1636
Cd	0.8	0.7	1.5	1.5	1.5	<0.0005	<0.0005
Co	-	-	-	-	-	0.0012±0.0001	0.0008±0.0001
Cr	70	70	90	90	90	0.008±0.0007	0.005±0.0004
Cu	70	70	100	100	100	0.0192±0.0007	0.0227±0.0004
Fe	-	-	-	-	-	3.0371±0.3175	1.2718±0.0605
K	-	-	-	-	-	35.2105±3.5726	79.8068±4.6271
Mn	-	-	-	-	-	0.1703±0.0033	0.0912±0.0011
Mo	-	-	-	-	-	0.0021±0	0.0004±0.0001
Ni	25	25	50	50	50	0.0049±0.0002	0.0041±0.0001
Pb	10	45	120	120	120	0.0016±0.0001	0.0011±0.0004
Sb	-	-	-	-	-	<0.0005	<0.0005
Se	-	-	-	-	-	<0.0006	<0.0005
Sn	-	-	-	-	-	0.0106±0.001	0.0106±0.0005
Ti	-	-	-	-	-	0.1411±0.0044	0.0814±0.0071
V	-	-	-	-	-	0.0044±0.0002	0.003±0.0001
Zn	200	200	400	400	400	0.0662±0.0073	0.0611±0.0067
Hg	0.1	0.4	1	1	1	<0.0005	<0.0005

Comparing the leaching properties of both pelletised biochar samples in Table 3-8, both samples are acceptable according to Australia's EPA standards and Singapore's NEA standards which are highlighted in pink. In general, the leaching results of potassium (K) is high in both biochar samples. However, Potassium element (K) is not considered a toxic metal pollutant [5]. Hence, both biochar samples are safe to be applied to the ground for agricultural use.

Table 3-8: TCLP Leaching Results for Both Pelletised Biochar

Leaching Elements	Leaching Limits (mg/kg)		Cotton Pellets Biochar (mg/kg)	Almond Hulls Pellets Biochar (mg/kg)
	Singapore NEA	**Australia EPA**	**650 - 750°C**	**650 - 750°C**
Al	-	-	1.46	1.14
As	5	20	0.0023	0.0013
Ba	100	300	0.1993	0.0087
Be	-	-	< 1	< 1
Ca	-	-	356.67	9.46
Cd	1	3	< 0.001	< 0.001
Co	-	170	< 0.001	0.0011
Cr	5	1	< 0.001	0.0017
Cu	100	60	< 0.001	0.2297
Fe	100	-	< 1	< 1
K	-	-	1235.81	3408.41
Mg	-	-	69.35	2.1
Mn	50	500	0.2719	0.0241
Mo	-	-	0.0125	0.0084
Ni	5	60	< 0.001	0.0055
P	-	-	26.58	9.32
Pb	5	300	< 0.001	< 0.001
Sb	-	-	< 0.001	< 0.001
Se	1	-	< 0.001	< 0.001
Sn	-	-	< 0.001	< 0.001
Sr	-	-	2.77	< 1
Ti	-	-	0.6093	0.0276
Tl	-	-	< 1	< 1
V	-	-	0.0023	0.0186
Zn	100	200	< 0.001	0.038
Hg	0.2	1	< 0.001	0.0013

3.6 Emission Limits Test

In Australia, the emission limits for flue gas from combustion sources such as power plants and waste-to-energy facilities are regulated by both federal and state environmental authorities. These regulations aim to minimize the release of harmful pollutants into the atmosphere. Below are the tests conducted on flue gas emitting out from BRE's system during cotton and almond feedstock run.

Table 3-9: Summary of Test Results carried out on 4/6/2024

Test Parameters	Australia's EPA Allowable Emission Limits (mg/Nm^3)	Almond Emission Results (mg/Nm^3)	Cotton Emission Results (mg/Nm^3)
Particulates	50	9.9	23.1
Carbon Monoxide	250	23.8	21
Oxides of Nitrogen (NO_x)	500	228	289
Sulphur Dioxide	1700	47.1	296
Hydrogen Chloride	10	< 0.2	< 0.2

Australia's environmental regulations are detailed in documents such as the National Environment Protection (Ambient Air Quality) Measure (NEPM) and various state-specific guidelines, like the New South Wales (NSW) Protection of the Environment Operations (Clean Air) regulation. These standards are enforced to ensure that the air quality is maintained and public health is protected. Continuous monitoring and reporting are often required to ensure compliance with these limits [1][2][3].

4 Conclusion

The Phase 2 test runs using almond and cotton feedstocks in BRE's system have provided valuable insights into performance, efficiency and areas for optimization. Both biochar samples underwent testing at a third-party laboratory to evaluate their properties, revealing that elemental content and TCLP results for both almond and cotton biochar samples meet the EBC's standards. However, the biochar from cotton pellets had an Oxygen to Organic Carbon molar ratio exceeding 0.4, which does not meet EBC requirements. In contrast, the biochar from almond hull pellets complies with EBC standards for both the Oxygen to Organic Carbon and Hydrogen to Organic Carbon molar ratios.

For the almond feedstock, steady-state syngas production yielded high LHV values ranging from 6.4 MJ/m^3 to 7.3 MJ/m^3, averaging around 6.85 MJ/m^3. The syngas flowrate stable between 40 to 60 m^3/hr was fully recycled into the burner, with no excess syngas introduced.

Conversely, the cotton feedstock exhibited LHV values ranging from 4.5 MJ/m^3 to 6.9 MJ/m^3, averaging approximately 5.9 MJ/m^3, indicating slightly lower energy content compared to almond feedstock.

However, the total syngas flowrate across all test runs averaged 80.85 m^3/hr, with syngas recycled to the burner averaging 59.81 m^3/hr and excess syngas averaging 21.04 m^3/hr, presenting an opportunity for cost effective utilization.

In this report, propane gas produced a power output of 15.492 kW due to its low required flowrate of 1.1 m^3/hr. On the other hand, excess cotton pellet syngas yielded a power output of 34.692 kW, which can be used to replace some or all of the propane gas to optimize the operating costs for the baler machine. However, for existing baler machines to utilize syngas instead of propane, conversion kits may be required. These kits typically involve modifications to the fuel injection system, ignition system and exhaust handling to accommodate the different properties of syngas.

Emission tests on both feedstocks confirmed compliance with Australia's EPA standards, demonstrating that pollutants released from BRE's system fall within acceptable limits. This ensures environmental compliance and contributes positively to air quality standards mandated by regulatory authorities.

In conclusion, the findings from Phase 2 testing underscore the BRE system's capability to produce biochar within regulatory limits while optimizing energy efficiency and potential resource utilization. These results pave the way for further refinement and scaling of operations, positioning BRE at the forefront of sustainable biochar production in alignment with environmental stewardship and operational efficiency goals.

5 References

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6 Appendix 1

MLS

TEST REPORT

Our Reference No.	:	**R240 4491**	Date of Monitoring	:	04/06/2024
Project Code / Ref.	:	-	Date Reported	:	18/06/2024

Customer Ref. No. : 20240524-01R1 (Bluefield)
Customer Name : Bluefield Renewable Energy Pte Ltd
Customer Address : 73 Ayer Rajah Crescent, #02-05/06
Singapore 139952

Attention To : Mr Isaac Yong

Subject : Source Emission Monitoring for Bluefield Renewables Energy on 04/06/2024.

Job Site : 22 Tuas Ave 6
Singapore 639309

Results : Refer to Page 3

Description : The results for all test parameters described in Table 3 of this report were within the Allowable Emission Limits, The Environmental Protection and Management Act (Air Impurities) Regulations 2015.

Toh Teck Yeow

Snr Manager, Env Services

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MLS

R240 4491

SCOPE OF WORK

Marchwood Laboratory Services Pte Ltd (MLS) performed source emission monitoring at 22 Tuas Ave 6 as described in the scope of work under Table 1. The tests were performed to determine if the emission levels were within the Allowable Emission Limits, The Environment Protection and Management Act (Air Impurities) Regulations 2015.

Table 1: Scope of Work

Location	Sample ID	Test Parameter	Date and Time of Sampling
22 Tuas Ave 6	Syngas Combustion Almond Feedstock	Particulates Carbon Monoxide Oxides of Nitrogen Sulphur Dioxide Hydrogen Chloride Methane Carbon Dioxide	04/06/2024, 1334hrs
	Syngas Combustion Cotton Feedstock	Particulates Carbon Monoxide Oxides of Nitrogen Sulphur Dioxide Hydrogen Chloride Methane Carbon Dioxide	04/06/2024, 1445hrs

TEST METHODS

Table 2: Test Methods

Test Parameter	Method
Particulate Matter	Gravimetric Method – Particulate Matter emission from stationary sources Sample was withdrawn with sampling pump at calibrated fixed flowrate and collected on a pre-weighed filter. The filter was then analysed gravimetrically.
Carbon Monoxide Oxides of Nitrogen Sulphur Dioxide Carbon Dioxide	TESTO 350 Flue Gas Analyser – Determination of Flue Gas Composition (Carbon Monoxide and Oxides of Nitrogen) A sample was withdrawn into an air bag from the emission source and analysed using TESTO 350 Flue Gas Analyser.
Hydrogen Chloride	Modified USEPA 26 – emissions from stationary sources Flue gas sample was withdrawn from the source into nalophane air bags using diaphragm pump at constant flowrate. The gas-filled air bags are then transferred into ultrapure water absorption solution using glass impingers with a calibrated sampling pump. The final impinged solution was then sent to lab for analysis by Ion Chromatography (IC).
Methane	GA5000 Landfill Gas Analyser – Determination of Methane Gas Composition A sample was withdrawn into an air bag from the emission source and analysed using GA5000 Landfill Gas Analyser.

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R240 4491

SUMMARY OF TEST RESULTS

Table 3: Summary of Test Results carried out on 04/06/2024

Test Parameters	Results, mg/Nm³ (corrected to 3% O_2)		Allowable Emission Limits, mg/Nm³
	Syngas Combustion Almond Feedstock (O_2 level: 13.42%)	Syngas Combustion Cotton Feedstock (O_2 level: 13.42%)	
Particulates	9.9	23.1	50
Carbon Monoxide	23.8	21.0	250
Oxides of Nitrogen	228	289	400
Sulphur Dioxide	47.1	296	1700
Hydrogen Chloride	< 0.2	< 0.2	200

Table 4: Summary of Test Results carried out on 04/06/2024

Test Parameters	Results, %	
	Syngas Combustion Almond Feedstock	Syngas Combustion Cotton Feedstock
Carbon Dioxide	15.39	12.55
Methane	0.3	0.3

Note:

1) mg denotes milligrams; Nm^3 denotes normal cubic meter, being that amount of gas which when dry, occupies a cubic meter at a temperature of 0 degree Celsius and at an absolute pressure of 760 mmHg of mercury.
2) It should be noted that all results obtained are based solely on the gas samples collected from that location, time and date as specified.
3) The results in Table 3 are corrected to 3% O_2 for boilers burning gaseous or liquid fuels in accordance to the EPM (Air Impurities) Regulations 2015.
4) "<" denotes "less than". The data reported was less than the detection limit of the test.

CONCLUSION

The results for all test parameters, listed in Table 3 of this report were within the Allowable Emission Limits, The Environmental Protection and Management Act (Air Impurities) Regulations 2015.

7 Appendix 2

Calculations

The calculations for propane gas flowrate were conducted with the following parameters:

Parameters:

- Production: 2200 bale/day
- Propane Gas Consumption: 12 L/bale

Total Propane gas consumption per bale:

$$2200\ \frac{bale}{day} \times 12\ \frac{L}{bale} = 26400\ \frac{L}{day}$$

Conversion of units to m^3/hr:

$$26400 \frac{L}{day} \times \frac{0.001}{1} \frac{m^3}{L} \times \frac{1}{24} \frac{day}{hr} = 1.1\ m^3/hr$$

The calculations for each fuel source were conducted with the following parameters:

1. Cotton Syngas:

- LHV: 5.9 MJ/m^3
- Syngas Flow rate: 21 m^3/hr

Total energy produced per hour:

$$5.9\ \frac{MJ}{m^3} \times 21 \frac{m^3}{hr} = 123.9\ MJ/hr$$

Power Output:

$$123.9\ \frac{MJ}{hr} \times \frac{1\ kW}{3.6 \frac{MJ}{hr}} = 34.692\ kW$$

2. Wood Chip Syngas:

- LHV: 12 MJ/m^3
- Syngas Flow rate: 21 m^3/hr

Total energy produced per hour:

$$12\ \frac{MJ}{m^3} \times 40\frac{m^3}{hr} = 480\ MJ/hr$$

Power Output:

$$480\frac{MJ}{hr} \times \frac{1\ kW}{3.6\frac{MJ}{hr}} = 134.4\ kW$$

3. Propane Gas:

- LHV: 50.3 MJ/m^3
- Fuel Flow rate: 1.1 m^3/hr (Calculations are shown in the Appendix to obtain this value)

Total energy produced per hour:

$$50.3\ \frac{MJ}{m^3} \times 1.1\frac{m^3}{hr} = 55.3\ MJ/hr$$

Power Output:

$$55.3\ \frac{MJ}{hr} \times \frac{1\ kW}{3.6\frac{MJ}{hr}} = 15.492\ kW$$