2019

Biomass Evaluation Report - SAMOA

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The Scientific Research Organisation of Samoa (SROS)

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Introduction

An extended biomass assessment study was scheduled this year under 'Improving the Performance and Reliability of RE Power System in Samoa' project (IMPRESS), to expand the range of feedstock for the biomass gasification plant currently under construction at Afolau. This study will encompass not only invasive trees but also hardwood for the main aim of determining optimum feedstock candidates. In addition, research data may aid decision making on managing plantations of fast-growing and high fiber yield species that can contribute to future alternative energy supplies.

In partnership with the Samoa Trust Estates Corporation (STEC), and the Ministry of Natural Resources and Environment (MNRE) – Renewable Energy Division (RED) and Forestry division – the most abundant invasive biomass types found at Afolau and well as hardwoods were brought in for analysis at the Scientific Research Organisation of Samoa laboratories (SROS) where the main parameters measured were calorific value and moisture content.

Biomass as fuel is a proven energy source and is selected on the basis of the calorific value of the fuel otherwise known as the heat value of the fuel. It is defined as the amount of heat released by burning of unit quantity of the fuel. (Bright Hub Engineering, 2019). Biomass with greater calorific value have the tendency to produce more power whereas biomass with less calorific value tend to burn inefficiently thus causing lots of exhaust and air-pollution. The heating value of a biomass is dependent on the state of water molecules in the final combustion products. When water is completely condensed out of the wood biomass during combustion, a higher heating value is produced. On the other hand, lower heating values stem from the water remaining as vapor in the final combustion products (Sokhansanj, 2011). Other factors that may influence heating value include the chemical composition of the individual biomass. The standard method of experimentally measuring the heating value of biomass fuels uses an oxygen bomb calorimeter device. The Scientific Research Organisation of Samoa was selected to conduct the analysis as they have the required expertise and facilities to conduct this research.

Further to a high energy content, other considerations when evaluating biomass involves evaluating for desirable wood qualities and ecological characteristics such as rapid rate of growth and adaptability to climatic conditions. An earlier feasibility study (2011) for this project identified years of low maintenance of the project site area, which has left the plantation overrun by fast growing indigenous and invasive species. The level of overgrowth was apparent during the frequent project site visits by the SROS and STEC team.

Objectives

The overall objective of this study is to identify ideal biomass feedstock for gasification. Specific objectives of this research are:

a) Characterization of potential feedstocks: test for moisture and calorific values. These properties indicated suitability of feedstock for gasification.
b) Characterization of the feedstock combinations: test for calorific values and determine drying time for the optimum combinations. Biomass combinations are a more realistic scenario of how the feedstock will treated as fuel for gasification.

Methodology

Site Assessment and Plotting

Guided by an earlier STEC plantation study (Forstreuter, W., 2016), SROS team in close collaboration with the IMPRESS/ STEC Team assessed the Afolau project site by:

1. Mapping out sampling sites based on its environmental layout and forest cover; and
2. Identifying most common plant species in each plot and approximating its percentage cover.

Figure 1 Biomass Sampling Plots, Afolau

Table 1 Field assessment of dominant plant species, taken from three plots throughout Afolau

Plot (100 m²)	Most Abundant Plant Species	Approximate % Cover
A	Pulumamoe	35
	Puluvao	25
	Faapasi	10
	Tamaligi/Lucinda	5
	Fau	5
	Niu	5
	Poumuli	5
	Mosooi	3
	Maota	2
	Other	5

B	Puluvao	35
	Pulumamoe	35
	Faapasi	10
	Fau	5
	Tamaligi/Lucinda	5
	Poumuli	2
	Nonu	1
	Papata	1
	Maota	1
	Other	5
C	Pulumamoe	40
	Puluvao	30
	Faapasi	10
	Tamaligi/Lucinda	5
	Fau	5
	Poumuli	3
	Nonu	1
	Niu	1
	Other	5

A preliminary site assessment of the STEC grounds in Asau, Savaii was also carried out by the IMPRESS/ STEC Feedstock Manager and SROS team, as an alternative source of feedstock for the gasification plant at Afolau.

Sample Collection and Preparation

Based on the site assessment exercise above, a total of six trees were randomly sampled from Afolau STEC lands. They are ***puluvao, pulumamoe, faapasi, fau, tamaligi*** and ***poumuli***. On a later date, MNRE-Forestry division submitted four additional samples of hardwood to be included in the analysis. These four samples are ***teak, lopa, malili*** and ***fiaifilele***. Lastly, a sample of ***lucinda*** was brought into the laboratory for analysis from the STEC Asau grounds in Savaii. Scientific names for each plant are outlined in Table 2.

For a period of 28 days in seven (7) day intervals, moisture readings as well as calorific values were analyzed for each individual species.

Table 2 Scientific Names of trees analyzed

Samoan Name	Scientific Name
Puluvao	*Funtumia elastica*
Pulumamoe	*Castill elastica*
Tamaligi	*Albizia falcataria*
Poumuli	*Flueggea flexuosa*
Lopa	*Adenanthera pavonina*
Malili	*Canarium vitiense*
Fiaifilele	*Instia bijuga*
Teak	*Tectona grandis*
Fau	*Hibiscus tiliaceus*
Fapasi	*Spathodea campanulata*
Lucinda	*Albizia chinensis*

Figure 2 Sampling at Afolau

Each tree trunk or branch was chipped on the same day of analysis using a wood chipper to approximately 4cm in length before being stored in airtight containers as shown in Figure 3. Meanwhile, the remaining trunks or branches were kept in a warehouse for air drying until the next assessment every seven days. In order to mimic the real time conditions of the biogas plant, the natural drying process was adopted to obtain realistic values for moisture content. Sample preparation for the bomb calorimeter required extra fine particles such as sawdust which was collected separately from the woodchips after passing the wood chipper. These were kept in airtight containers to preserve the condition of the samples. When evaluating the combinations, the ratios used were measured accordingly from the samples previously prepared before submission to the laboratory for analysis.

Figure 3 Logs and fine chips from wood chipper

Sample Analysis

Moisture Content

Moisture content is calculated by the difference in weights after 7 days of drying. Chips are weighed initially after preparation then left to dry for seven days before being weighed again. The formula for calculating moisture content is given below.

<u>Formula for finding moisture content:</u>

$Moisture\ \% = \frac{(Wi - Wf)}{Sample\ wt} x\ 100$ Where wi is initial weight and wf is final weight both in grams.

Calorific value

The extra fine particles and sawdust collected from the wood chipper are pressed into pellets then weighed. Initially, the calorimeter is calibrated by combustion of certified benzoic acid to determine the effective heat capacity of the device. Next, the pellets are then burned in high-pressure oxygen in a bomb calorimeter under specified conditions where temperature readings are taken at regular one minute intervals during and after combustion (SIS-CEN/TS14918:2005, 2010). The energy content can then be calculated using the formula stated below.

<u>Formula for finding Energy Content:</u>

Energy per ^{0}C = 2345 calories/^{0}C

1mL Na_2CO_3 = 1 calories

Energy per cm (fuse wire) = 2.3 calories

Conversion factor: 1 kcal = 4.186 kJ

$$Energy\ content\ (\frac{kJ}{g}) = \frac{(temp\ diff\ x\ Energy\ per\ °C) - (BFW\ x\ Energy\ per\ cm) + (titre\ vol\ Energy)}{sample\ weight\ (grams)}$$

Selection of Combinations

The selection of most appropriate feedstock combinations was finalized through discussions between ERED and the Feedstock Manager of IMPRESS, based on:

- Information collected from field studies of the project site (for e.g., abundance, regrowth period etc.)
- Individual calorific and moisture values of the potential feedstock species

From the results of actions above, the feedstock combinations were selected in the following ratios:

- Puluvao + pulumamoe + faapasi (1.16:1.16:1)
- Puluvao + pulumamoe + lucinda (1.16:1.16:1)
- Puluvao + pulumamoe (1:1)
- Puluvao + poumuli (1:1)

The biomass combinations were made using wood chips of the selected plant species, after drying for 14 days. The drying period was selected as recommended by the Feedstock Manager based on the most likely real-world conditions of biomass preparation for the gasification plant. Once the biomass combinations were thoroughly mixed, calorific testing was carried out using the same procedure as outlined above.

Results

Tree samples taken from Afolau STEC land as well as hardwoods sourced by the Forestry Division of MNRE were analyzed locally at SROS laboratories for calorific values and moisture content. Below are the tables of results for each species tested over four consecutive drying periods of 7 days.

Table 3 Calorific Value and moisture content of Afolau samples

FAAPASI				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	16.56	12.92	6.20	5.18
Calorific Value (kJ/g)	0.74	7.42	10.12	11.66

FAU				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	10.28	10.74	9.13	5.95
Calorific Value (kJ/g)	9.54	11.67	13.15	13.74

POUMULI				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	12.48	8.62	4.52	4.73
Calorific Value (kJ/g)	13.89	13.59	13.26	18.31

PULUMAMOE				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	17.81	12.81	16.38	15.71
Calorific Value (kJ/g)	8.14	9.32	5.15	9.25

PULUVAO				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	10.34	8.29	7.34	4.12
Calorific Value (kJ/g)	11.1	12.44	13.02	12.09

TAMALIGI				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	13.46	8.99	8.98	8.38
Calorific Value (kJ/g)	11.76	13.3	12.57	13.75

LOPA				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	9.23	7.30	3.66	3.65
Calorific Value (kJ/g)	13.13	13.93	12.39	9.46

FIAIFILELE				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	11.46	8.04	5.83	5.13
Calorific Value (kJ/g)	11.79	13.67	14.13	11.05

TEAK				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	12.11	12.79	10.14	9.46
Calorific Value (kJ/g)	8.57	9.48	6.55	9.34

MALILI				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	7.49	6.86	4.68	3.34
Calorific Value (kJ/g)	9.78	12.48	12.67	10.96

LUCINDA				
ANALYSIS	Drying Period (Days)			
	7	14	21	28
Moisture (%v/v)	6.33	2.11	2.11	-
Calorific Value (kJ/g)	13.52	14.35	12.23	12.61

Table 3 above presents the readings of moisture and calorific values for the trees selected and sampled. The data shows a general trend of an increase in calorific value when moisture value decreases. Additionally, samples with moisture content greater than 10% demonstrate a lower calorific value compared with drier samples with less than 10% moisture. This tendency applies for both soft wood invasive species as well as local hardwoods. Also, it can be seen that hardwoods typically hold a higher heating value compared with soft fibrous trees.

Moisture Content of Individual Biomass Samples

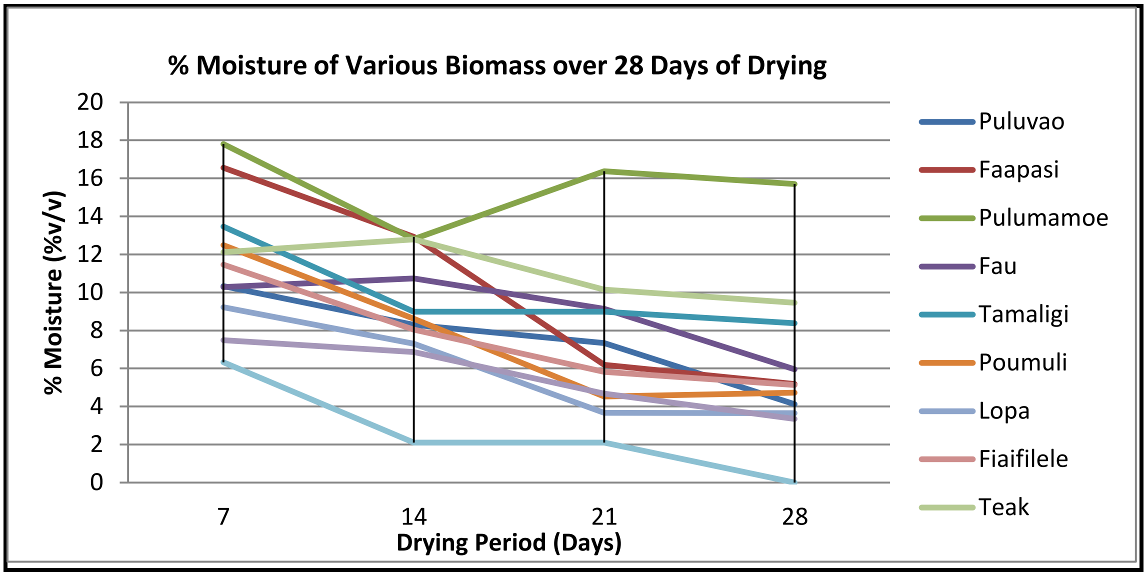

Figure 4 Graph of % Moisture Values of Tested Biomass Samples over a 28 Day Drying Period

Figure 4 above allows for the direct comparison of percentage moisture values for the different biomass varieties. It can be seen that three biomass samples fall below 10% moisture (lucinda, malili, and lopa) after only 7 days of drying, and the majority of biomass samples (seven out of the eleven) fall below 10% after 14 days of drying.

Energy Content of Individual Biomass Samples

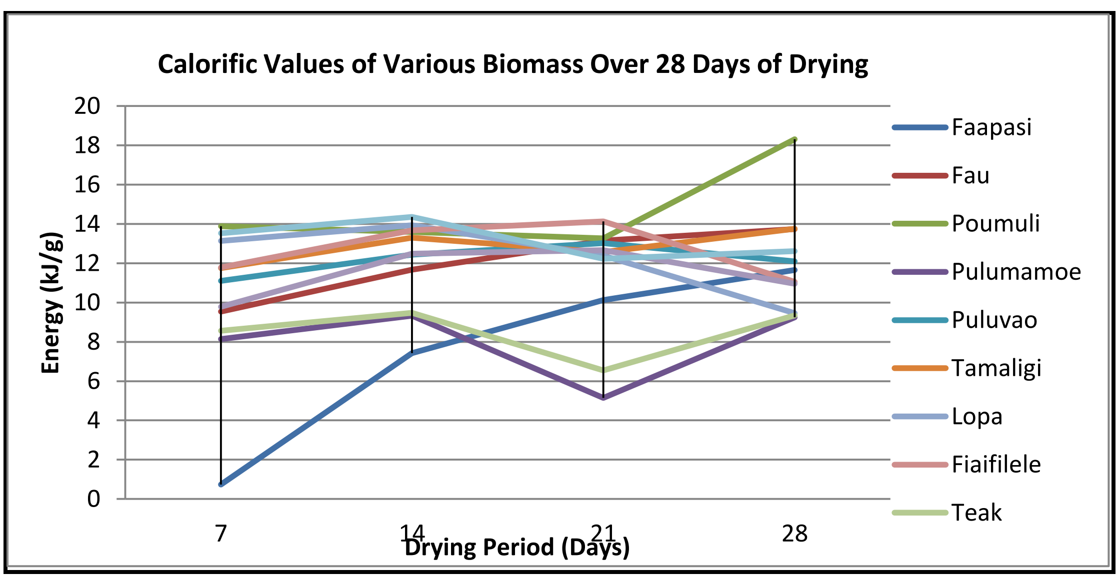

Figure 5 Energy values of biomass samples over a 28 Day Drying Period

Figure 5 illustrates calorific values of each biomass type over the 28 days drying period, and highlights well that most biomass samples show relatively little or insignificant rises in energy values when dried longer than 14 days.

Figure 4 and 5 also allows for the comparison between moisture content and energy values of each biomass type, and it was interesting to see that in some cases, biomass samples with lower moisture content do not necessarily have the highest value. This can be seen for malili, teak, fiaifilele, lopa and poumuli.

Moisture vs Energy Values

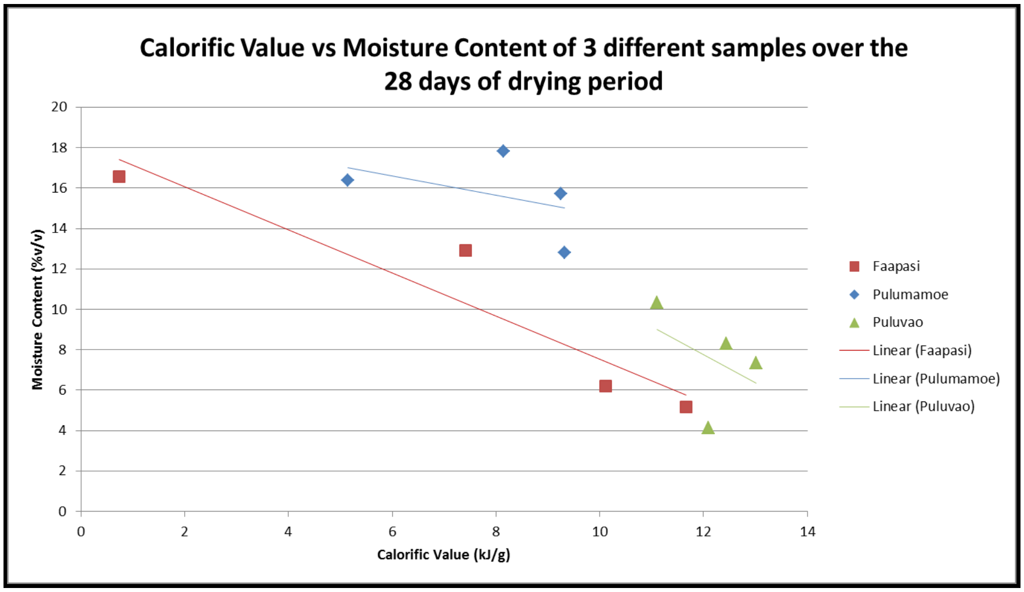

Figure 6: Calorific vs Moisture content for the three most common species - pulumamoe, puluvao and faapasi

Figure 6 above shows focusses on the three most common invasive species of the study area - pulumamoe, puluvao and faapasi – showing decreasing moisture content values corresponding to increasing calorific values throughout the drying period of 28 days. These three common species are potentially the main feedstock for the gasifier.

Biomass Combination Values

Table 4 Calorific Values from local analysis of feedstock combinations

Combinations	Calorific Value (kJ/g)
	Day 14
Puluvao + Pulumamoe + Fapasi	9.91
Puluvao + Pulumamoe + Lucinda	10.02
Puluvao + Pulumamoe	10.35
Puluvao + Poumuli	11.97

Table 4 on the other hand, displays the calorific value for the feedstock combinations most likely to be used for the Biogas Gasification Plant. As seen in the table above, aside from the 'Puluvao + Poumuli' combination, the calorific values do not differ greatly with an average reading of 10.09kJ/g for the first three combinations after drying in the shed for two weeks.

The feedstock combination wood chips were also sent overseas for a complete biomass analysis which includes a range of parameters from ash to volatile solids and other elements. The complete set of results can be found in Appendix 1 while the calorific values and moisture content analyzed overseas are given below in Table 5 as received. Note the method of analysis for both parameters differs from the local testing methods thus the differences in values. Moisture analysis conducted overseas utilized a drying oven at 105°C while the determination of calorific value was by the bomb calorimetric method and calculation of the net calorific value.

Table 5 Calorific Values from overseas analysis of feedstock combinations

Combinations	Calorific Value (kJ/g)
	Day 14
Puluvao + Pulumamoe + Fapasi	16.42
Puluvao + Pulumamoe + Lucinda	16.40
Puluvao + Pulumamoe	16.25
Puluvao + Poumuli	16.61

Figure 7 shows a comparison of the different combinations samples. As seen in the graph, there is a slight increase in the calorific value for the combination containing Poumuli. This was anticipated as Poumuli is a hard wood with higher density and is therefore expected to have higher energy content. The other combinations remain fairly constant in their calorific values.

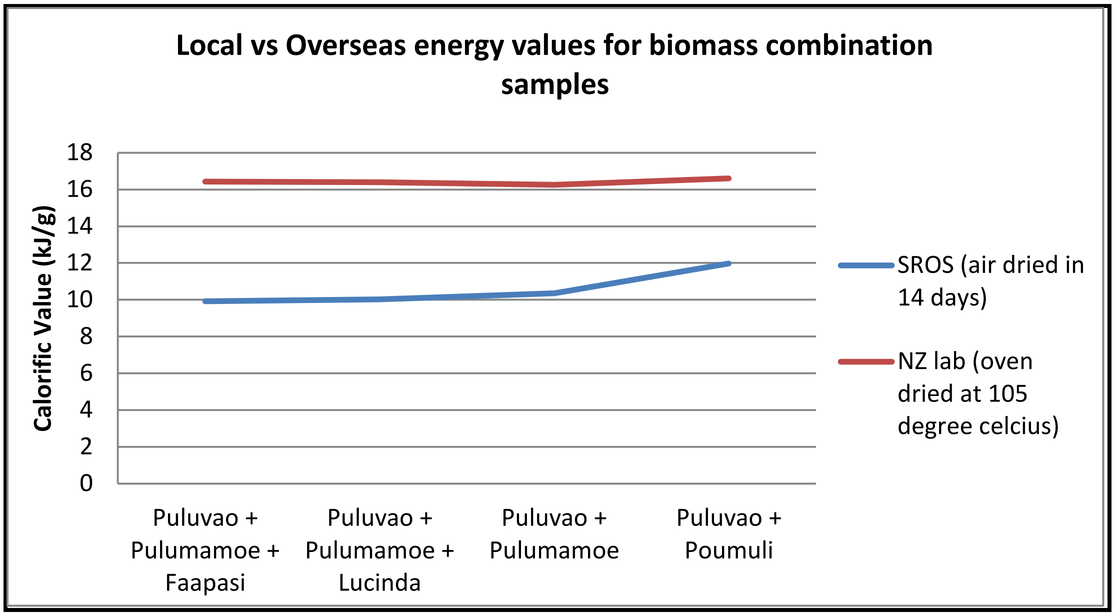

Figure 7 Local vs overseas energy values for biomass combination samples

Discussion

Moisture content of biomass feedstock is important for many reasons when considering its fuel ability. For a moist fuel, the heating value decreases because a portion of the combustion heat is used up to evaporate moisture in the biomass and this evaporated moisture has not been condensed to return the heat back to the system (Sokhansanj, 2011). Increasing moisture content diminishes the net heat value of biomass to the point that at slightly higher than 80% moisture content, much of the heat content of the biomass is used up to evaporate its moisture (Sokhansanj, 2011). Literature discusses varying percentage moisture values recommended to minimize energy losses in the overall process. Typically, drying biomass to 10-20% moisture content is considered the optimum for minimizing negative impacts on a gasification plant (Nooruddin, 2011). Others such as Peres et al (2013) outline that the gasification process is applicable for biomasses that possess moisture content lower than 35%. Despite the variation in recommended biomass moisture values, what is agreed upon is that the lower the moisture content, the greater the potential for gasification process.

It was therefore important for this study to trial different drying periods to obtain an estimated time for the moisture content to drop to 10% or less. From the results displayed in Table 2, two weeks is sufficient time for most of the samples to reach this goal. Consultations with the IMPRESS Feedstock Manager in relation to the most likely conditions of the feedstock illustrated that realistically, drying time would be no longer than 14 days. Moisture analysis results for the potential feedstock is therefore positive in that moisture levels reached at 14 days is below or close to 10%.

Assessing each potential feedstock individually is crucial to gauge drying time required to reach the ideal moisture content as well as calorific output. Assessing the feedstock in combinations allows for analysis of fuel potential across different combinations of the target feedstock. Assessing of feedstock combinations also allows for the analysis of the most likely real life situation of the gasification plant, whereby biomass harvesting won't be limited to a particular species, but rather a combination of the most abundant species on STEC lands such as the puluvao and pulumamoe. These most common as the most abundant biomass type will therefore be the target feedstock for the Afolau Gasification Plant, with the potential to mix in other plants when harvested like the tamaligi/lucinda, faapasi and fau, as they're also relatively abundant.

Additionally, a combination study allows for the observation of calorific output with and without the inclusion of hardwoods in the combinations. However this study indicates that the effect is miniscule with almost negligible difference between combinations. Overseas analysis also reflects this trend and demonstrates a fairly constant calorific value between different feedstock combinations. This may be due to the fact that the prime species of puluvao and pulumamoe were used in all combinations.

Reviewing previous studies on the woody properties of different biomass feedstock candidates allow for a comparison with our study results. The average calorific value of a hard wood plant species the Black Locust for example was studied and valued at 18.45kJ/g (Geyer, 2007). Another hard wood the White Ash was given as 16.26kJ/g by Arola (1976), and an average value of a variety of hard wood was given in a study by Panshin and deZeeuw (1970) to be 19.76kJ/g. These previous studies give a range of values from 16.26kJ/g – 19.76kJ/g for hard woods with calorific values acceptable for gasification.

The results of this study give a range of 12.44kJ/g (Puluvao) to 14.35kJ/g (Lucinda) for some of the most common plant species found within Afolau. This value range may still be considered as high seeing as the plant species targeted are non-hard woods and therefore expected to have considerably lower calorific values. The average value for combinations analyzed at SROS was 10.56kJ/g, lower than the average value for combinations analyzed in the NZ laboratory – 16.42kJ/g – which was well within the value range of previous biomass hard wood studies. The difference in results for the SROS and overseas laboratory is largely attributed to the treatment method (chipping and drying) applied to the biomass samples. This difference in how the biomass feedstock is treated (logs vs fine wood chips/ air dried vs oven dried etc.) could therefore be a consideration when preparing the feedstock for gasification process.

Conclusion

To conclude, the moisture content of wood is one of the factors that affect its calorific value when it undergoes combustion. Wetter samples tend to have a slightly lower calorific value as some of the energy is used up to evaporate the water. This study shows that drying naturally in a shed for two weeks will meet the minimum requirement of 10% moisture content of the feedstocks. This is when the calorific values of the feedstock begin to increase compared to fresh samples. Thus the recommendation to only used feedstock that has been dried for at least two weeks to feed the biomass gasification plant for optimum performance and energy efficiency.

Furthermore, feedstock combinations have a minor effect on calorific value as the individual species' heat value is relatively close to the combinations tested whereas the different combinations show almost no difference between them. The species selected for the feedstock combination study are predominantly puluvao and pulumamoe which may account for the relatively close values per combination.

Lastly, results illustrate that the main varieties in abundance within Afolau – Pulumamoe, Puluvao, and Faapasi – when combined, have an energy output comparable to other woody biomass previously tested in other studies, and concluded to be suitable for gasification.

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Appendix 1

REPORT OF ANALYSIS

Customer: Scientific Research Organisation of Samoa | **Date Received:** 14-Aug-19

Description: Biomass samples provided by Client

Customer Reference:		**Puluvao / Pulumamoe**	**Puluvao / Pulumamoe / Faapasi**	**Puluvao / Poumuli**	**Lopa**	**Malili**	**Puluvao / Pulumamoe / Tamaligi**
Sample Weight (kg)		500g	650g	500g	1680g	740g	510g
CRL Energy Ltd Reference:		19/1045-1	19/1045-2	19/1045-3	19/1045-4	19/1045-5	19/1045-6
Analysis - As Received Basis							
Moisture (Loss on Drying 105C)	%	16.5	16.8	16.7	16.2	16.5	16.4
Ash (ASTM D1102)	%	2.3	2.1	1.6	1.4	1.5	2.2
Volatile (ISO 562)	%	64.6	63.3	64.9	66.4	66.5	64.6
Fixed Carbon (by difference)	%	16.6	17.8	16.7	16.1	15.5	16.8
Gross Calorific Value (ISO 1928)	MJ/kg	16.25	16.42	16.61	16.76	16.56	16.40
Sulphur (ASTM D4239)	%	0.09	0.06	0.04	0.02	0.02	0.07
Carbon (ASTM 5373)	%	41.7	41.8	42.1	41.8	41.6	40.8
Hydrogen (ASTM D5373)	%	4.95	5.00	5.07	5.09	4.90	4.87
Nitrogen (ASTM D5373)	%	0.35	0.35	0.29	0.31	0.20	0.46
Oxygen (by difference)	%	34.0	33.8	34.2	35.2	35.3	35.1
Analysis - Dry Basis							
Ash (ASTM D1102)	%	2.8	2.5	1.9	1.6	1.8	2.6
Volatile (ISO 562)	%	77.3	76.1	78.0	79.2	79.6	77.3
Fixed Carbon (by difference)	%	19.9	21.3	20.1	19.2	18.6	20.1
Gross Calorific Value (ISO 1928)	MJ/kg	19.5	19.7	19.9	20.0	19.8	19.6
Sulphur (ASTM D4239)	%	0.11	0.08	0.05	0.02	0.02	0.08
Carbon (ASTM 5373)	%	50.0	50.3	50.5	49.9	49.8	48.9
Hydrogen (ASTM D5373)	%	5.93	6.01	6.08	6.07	5.86	5.83
Nitrogen (ASTM D5373)	%	0.42	0.42	0.35	0.37	0.24	0.55
Oxygen (by difference)	%	40.8	40.7	41.1	42.0	42.3	42.1

Date of Issue: 11-Sep-19

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