



# Forest Research

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## TECHNICAL DEVELOPMENT

### INTERNAL PROJECT INFORMATION NOTE 28/07



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## Calorific Value of Brash Bales

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### Calorific Value of Brash Bales

#### SUMMARY

Analysis of the energy value of brash bales produced using three separate presentation methods confirmed the assumptions made in Internal Project Information Note (IPIN) 17/06 *Presentation of Brash for Baling from Clearfell Harvesting* (Webster 2007).

Bales containing delimbed stemwood from small diameter tops had a significantly higher calorific value (12–14 MJ/kg at 23–31% MC) than those containing both branchwood and stemwood (7–10 MJ/kg at 44–55% MC). The stemwood bales also contained significantly less nitrogen (0.3–0.4%) than either green or brown baled brash (0.6–0.9%), and when burned produced significantly less ash (0.4–0.5% compared with 1–3%).

These results suggest that recovery of stemwood rather than brash should be preferred for woodfuel production, for both economic and environmental reasons.

#### INTRODUCTION

Investigation of woodfuel production from brash baling, detailed in IPIN 17/06, studied the production of bales from three different brash presentation methods:

- 100% branchwood and small diameter tops placed in the brash mat (conventional practice) and every second brash mat baled.
- Whole small diameter tops, equivalent to 50% of available tops, placed in a distinct brash zone for baling.
- Delimbed small diameter stemwood ('delimbed tops'), equivalent to 50% of available stemwood in tops, placed in a distinct brash zone for baling.

The three resulting products were baled in two stages, half while still green, and the other half after 6 months when substantial needle loss was judged to have occurred.

The results demonstrated that the highest outputs, in terms of apparent<sup>1</sup> volume production from harvesting and the number of bales subsequently produced per hour, were achieved when the harvesting method was unaltered and a conventional brash mat was baled. However the study also found that the solid<sup>2</sup> volume of a bale appeared to be substantially greater when delimbed tops were baled.

The report concluded that the best method of woodfuel production was from delimbed tops, as the method had a greater output in terms of solid volume, weight and energy value than the other two methods. The calculations of energy values were derived from existing data for solid wood, however, and a more reliable comparison was needed to confirm the findings.

#### METHODS

For the current project, an indication of the calorific value of the brash bales was obtained by chipping a sample of four bales from each treatment and extracting sub samples for analysis. In addition, the proportion of nitrogen in each sample and of major elemental oxides contained in the ash was quantified.

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<sup>1</sup> The 'apparent' volume of a bale is the volume obtained by multiplying its section by its length

<sup>2</sup> The 'solid' volume is the real volume of material in the bale determined by immersion in water

This report details the chipping and sampling methods used and the results obtained from analysis carried out by TES Bretby (address given in Appendix A, page 8), an accredited testing laboratory.

### **Material and sampling**

The site, at Cae Weirglodd in Clocaenog forest, had been clearfelled a year prior to the study, the green brash being baled eleven months and the brown brash four months prior to chipping. The previous crop was P53 Sitka spruce, which had been line thinned, leaving an average of 1210 trees per hectare, with an average tree volume of 0.45 m<sup>3</sup>, at final felling.

Bales from each treatment had been stacked separately at roadside, and four individual sample bales were selected at random from each treatment. The green bales were identified with the prefix 1 and the brown with the prefix 2, whilst the presentation methods were identified with the letters NBR for 100% brash, BR for 50% whole tops and RS for 50% delimbed tops.

### **Chipping**

The selected bales were processed individually using a Heizohack HM8 400 drum chipper, which was mechanically fed using a tractor driven Farmi hydraulic loader (Plate 1). The chipper is designed to produce a consistently sized woodfuel chip and is fitted with interchangeable grading screens. The screen used on this occasion had apertures of 35x40 mm designed to produce G50 chips as specified in the Onorm M 7133 standard (CEN 1999).

**Plate 1** Chipper and loader



The binding twine used to secure each bale was cut away to allow the loader operator to separate the bale into manageable grabfuls and place each grabful into the chipper infeed hopper. This process, combined with the fact that, once material was placed in the hopper, the conveyor infeed took up material at an uneven rate, with some remaining in the hopper until dragged through by the next grabful, ensured that the contents of the bale were well mixed before being chipped. Some further mixing occurred during the chipping process itself, as some material was blocked by the grading screen on the first pass and was recirculated through the drum chamber.



The chipper outflow was positioned over a plastic tarpaulin and samples taken from the heap of chips formed once the complete bale had been processed. The remaining material was then cleared away before the next bale was chipped, so that each heap contained only the contents of one individual bale. It was apparent during chipping that the RS bales (delimbed tops) produced relatively consistent woodchips. When chipping bales from the other treatments, in particular the NBR bales (100% brash), a more amorphous, compost like material was produced (Plate 2).

**Plate 2** Material produced when chipping 100% brash



### **Sampling of the chips**

Sampling of individual heaps was carried out in accordance with the protocol detailed in draft standards for solid biofuels (CEN 2005a). Eleven 3.15 litre shovelfuls of chips were taken from regularly spaced points throughout the heap and bagged together to give a mixed sample volume approximately equivalent to 35 litres from each chipped bale. Bags were closed and tagged with the treatment identifier and numbered 1 to 4, prior to being transported to the testing laboratory. In all, 24 chipped bales were sampled in this way.

### **Sample analysis**

The analysis of samples was carried out in accordance with the protocols detailed in draft European standards for the determination of moisture content (CEN 2004a), Nitrogen (CEN 2005b) calorific value (CEN 2005c), ash content (CEN 2004b) and major elements (CEN 2006) in solid biofuels.

The original objective, as stated above, was to assess the variation in calorific value between treatments. However consultation with Tom Nisbet, FR Environmental and Human Sciences Division, identified a need for an indication of the potential effects of brash removal on site fertility and potential to buffer acidity. It was decided therefore that further analysis of potential plant nutrients and base elements contained in the samples would be useful. The sampling had not been designed to allow statistical analysis of the variation in levels of these elements: These opportunistic measurements were intended simply to provide an indication of trends.

The protocols set out in the draft standard for the determination of major elements in solid biofuels (CEN 2006) provide for measuring up to 11 major oxides, plus sulphur and minor elements. Of these, the most important elements for site fertility are Potassium and Phosphorus, while those most important for buffering acidity are the base elements Calcium, Magnesium, Potassium and Sodium (Nisbet, unpublished). Nitrogen, the other important element in terms of plant growth, was measured using a separate method (CEN 2005b).

### Statistical Analysis

Differences between brash bale treatments in terms of calorific value, ash and major element composition were analysed by analysis of variance (ANOVA). Although 4 replicates of each brash bale treatment were collected it was considered inappropriate to treat them as true replicates as identical genetic material was likely to be a component of a number of brash bales forming the same treatment. Consequently replicate information was combined and simply the interaction between bale type and colour (brown/green) used to test for differences between treatments.

## RESULTS

The detailed results of these analyses are presented in Appendices. Table 1, below, summarises the results of the determination of moisture content, calorific value and sulphur content. The determination of sulphur content at this stage is necessary as the volatilisation of sulphur during burning contributes to the gross calorific value. The values for the four samples from each treatment have been averaged to give a mean value per treatment.

**Table 1** Average values for moisture content, calorific value and sulphur content for each treatment

	1NBR (100% brash baled green)	1BR (Whole tops baled green)	1RS (Delimbed tops baled green)	2NBR (100% brash baled brown)	2BR (Whole tops baled brown)	2RS (Delimbed tops baled brown)
MC %	44.05	46.08	22.63	54.15	55.05	30.58
Sulphur % sample wt	0.03	0.02	0.02	0.03	0.03	0.01
Gross CV (MJ/kg)	11.62	11.15	15.83	9.63	9.33	13.94
Net CV (MJ/kg)	9.92	9.40	14.32	7.86	7.48	12.33

Although the calorific value of the NBR and BR samples was similar, the RS samples (delimbed tops) from both stages of baling had a substantially higher calorific value than the samples from the other two treatments ( $p < 0.001$ ), largely due to their lower moisture content. Less predictably, the moisture content of the brown bales was actually higher than that of the green bales ( $p < 0.001$ ).

Removing the effect of moisture content by looking at the dry calorific value confirmed the observed difference between the treatments (Table 2). The net CV of the RS samples was significantly higher (4–7%) in comparison to the other two treatments for both brown and green bale treatments ( $p < 0.01$ ).

**Table 2** Average calorific values (dry sample) for each treatment

	1NBR	1BR	1RS	2NBR	2BR	2RS
Net CV (MJ/kg)	17.67	17.33	18.51	17.14	16.56	17.74

The RS samples also produced far less ash when burned, as can be seen in Figure 1. The quantities are expressed as a percentage of dry sample weight.

**Figure 1** Proportion of ash (% dry sample weight) produced on burning

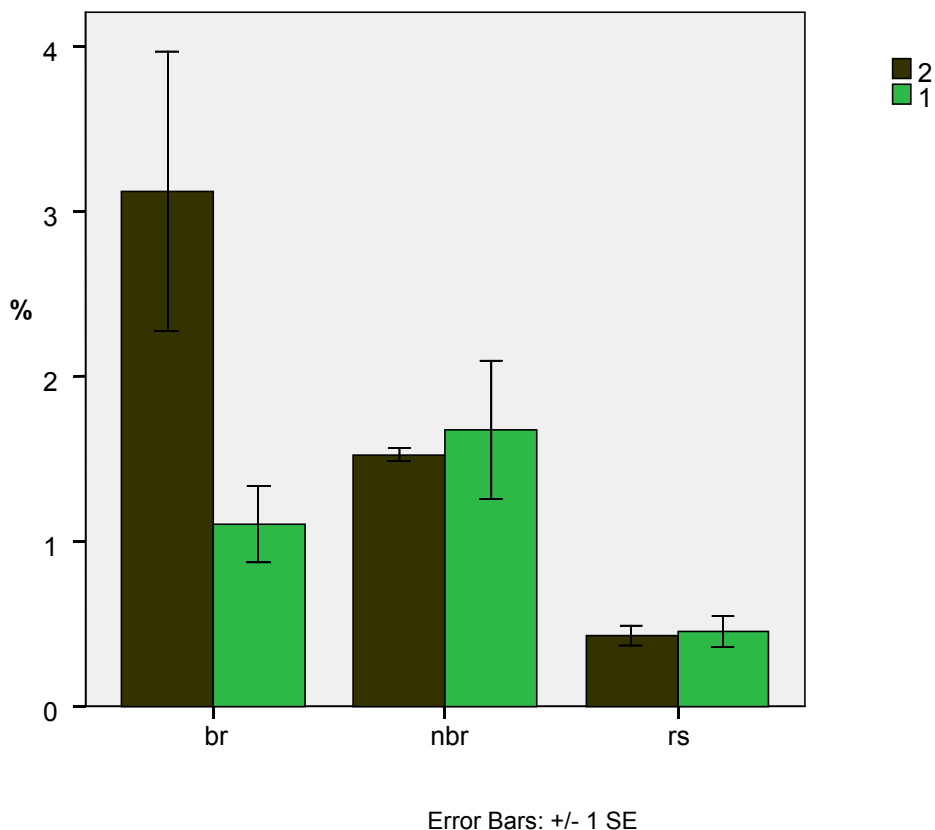


Table 3 summarises the proportions of Nitrogen in the samples and major elements contained in the ash produced. Again, the values have been averaged for each treatment.

To allow direct comparison, the average percentage of Nitrogen in samples has been expressed as a percentage of dry weight. Similarly, other elements have been expressed as % of ash by dry weight in the samples to give an absolute value for each element.

**Table 3** Proportions of nitrogen and major elements (% dry sample weight) in samples

	1NBR	1BR	1RS	2NBR	2BR	2RS
Nitrogen N	0.79	0.63	0.37	0.92	0.93	0.33
Calcium CaO	0.28	0.22	0.12	0.39	0.34	0.11
Magnesium MgO	0.10	0.08	0.05	0.10	0.15	0.04
Sodium Na <sub>2</sub> O	0.03	0.03	0.01	0.03	0.06	0.01
Potassium K <sub>2</sub> O	0.15	0.13	0.05	0.20	0.28	0.03
Phosphorus P <sub>2</sub> O <sub>5</sub>	0.07	0.06	0.03	0.11	0.12	0.02

The most important differences were in the amount of Nitrogen in samples and in the amount of ash produced (Figure 1), which determined the absolute proportions of all other measured elements in the samples. Differences between treatments in terms of the relative levels of plant nutrients and base elements in the ash are shown in Appendix B, but were unimportant compared to the larger differences in absolute quantities in samples.

Table 3 shows that the proportion of Nitrogen in the RS samples was substantially less than in samples from the other treatments. For both green and brown baling the total amounts of all other measured elements were also smaller in the RS samples than in those from the other treatments, due to the fact that far less ash was produced.

## **Discussion**

While the difference in Calorific value and Nitrogen content is significant and consistent between the RS and the other two treatments, differences between treatments in terms of the relative proportions of other elements and between green and brown baling are less clear. Levels of N, for example, were actually higher on average in samples from the brown baled BR treatment, even in proportion to wet weight (Appendix A).

### Soil nutrients

The precise composition of the bales, in terms of the relative proportions of whitewood, bark, brown and green needles, is unknown. Differences between individual bales may mask some of the differences between treatments. The importance of differences between treatments should also be related to the site, in terms of the total amounts of each element removed by area relative to the background soil nutrient status of the site.

### Moisture content

The brown bales had a higher initial moisture content than the green bales, and therefore a lower calorific value, despite being baled in summer rather than winter. This is almost certainly due to the exceptionally heavy and persistent rain during June/July 2007, which would have saturated the brown brash just prior to baling in mid July.

The green bales appear to have been affected less by this rainfall. One reason for this may be that older material, having begun to degrade, absorbs moisture more readily and is more prone to rewetting. Probably more important is the fact that the green brash had been baled and stacked at roadside earlier, which would have limited rain penetration and protected much of the material from subsequent rewetting.

It is likely that the moisture content would have fallen again had the brown brash been left over summer. This highlights an important logistical consideration in all woodfuel production, in that the timing of extraction and stacking or removal to storage is critical to achieving a high value product.

## **CONCLUSIONS**

These results support the assumptions of the previous study IPIN 17/06, which concluded that bales containing delimbed tops had a higher calorific value than those containing whole brash, whilst their removal would have less of an impact on the overall nutrient capital of the site.

The advantages of delimbed stemwood over whole brash removal are greatest when considered on a 'per bale' basis, as the RS bales contain up to 20% more solid biomass according to the findings reported in IPIN 17/06.

## **RECOMMENDATIONS**

Delimbed stemwood should be used for biomass fuel production in preference to branchwood brash, as this material allows greater outputs at the harvesting stage and produces bales of greater calorific value than brash.

Future trials of brash bale production should assess the solid volume of biomass contained in bales, as well as moisture content, to determine their energy value.

Further work should be undertaken to examine the potential impacts of the different types of brash removal in terms of soil nutrient and pH status.



## ACKNOWLEDGEMENTS

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## BIOFUEL CHIP SAMPLE ANALYSIS

Date Analysed: 21<sup>st</sup> November to 17<sup>th</sup> December 2007

Sample Reference	1BR - 1	1BR - 2	1BR - 3	1BR - 4	1NBR 1	1NBR 2
Total Moisture %	52.5	50.8	52.4	28.6	43.2	49.9
Ash %	0.5	0.6	0.8	0.4	0.5	1.0
Sulphur %	0.02	0.02	0.02	0.01	0.02	0.03
Gross Calorific Value kJ/kg	9984	10034	9909	14660	11748	10513
Net Calorific Value kJ/kg **	8227	8220	8079	13066	10018	8784
Nitrogen %	0.41	0.28	0.38	0.21	0.39	0.52
<b>Test results calculated to "As received" Moisture Basis</b>						

Sample Reference	1NBR 3	1NBR 4	1RS 1	1RS 2	1RS 3	1RS 4
Total Moisture %	49.3	33.8	21.0	21.5	25.1	22.9
Ash %	1.4	0.8	0.5	0.2	0.5	0.3
Sulphur %	0.02	0.03	0.02	0.01	0.02	0.01
Gross Calorific Value kJ/kg	10451	13763	16323	15909	15333	15765
Net Calorific Value kJ/kg **	8723	12143	14834	14394	13806	14261
Nitrogen %	0.40	0.42	0.34	0.23	0.31	0.26
<b>Test results calculated to "As received" Moisture Basis</b>						

Sample Reference	2BR 1	2BR - 2	2BR - 3	2BR - 4	2NBR 1	2NBR 2
Total Moisture %	48.3	58.8	51.1	62.0	55.2	51.8
Ash %	0.9	0.9	1.5	2.1	0.7	0.7
Sulphur %	0.03	0.03	0.03	0.04	0.03	0.02
Gross Calorific Value kJ/kg	10804	8593	10031	7898	9457	10165
Net Calorific Value kJ/kg **	9002	6702	8227	5980	7655	8482
Nitrogen %	0.41	0.40	0.38	0.45	0.42	0.45
<b>Test results calculated to "As received" Moisture Basis</b>						

Sample Reference	2NBR 3	2NBR 4	2RS 1	2RS 2	2RS 3	2RS 4
Total Moisture %	54.1	55.5	31.5	24.9	29.5	36.4
Ash %	0.7	0.7	0.3	0.2	0.4	0.3
Sulphur %	0.03	0.03	0.01	0.01	0.01	0.01
Gross Calorific Value kJ/kg	9585	9324	13756	15128	14194	12687
Net Calorific Value kJ/kg **	7803	7510	12130	13578	12595	11007
Nitrogen %	0.44	0.38	0.22	0.23	0.25	0.22
<b>Test results calculated to "As received" Moisture Basis</b>						

\*\* Calculated using determined values

Elemental Oxide	Sample Reference											
	1BR 1	1BR 2	1BR 3	1BR 4	1NBR 1	1NBR 2	1NBR 3	1NBR 4	1RS 1	1RS 2	1RS 3	1RS 4
SiO <sub>2</sub>	28.3	42.0	35.9	22.4	33.0	43.7	50.5	27.0	34.2	25.4	26.2	19.7
Al <sub>2</sub> O <sub>3</sub>	5.3	7.9	8.0	6.1	6.4	9.0	12.3	6.1	3.9	5.9	5.8	6.5
Fe <sub>2</sub> O <sub>3</sub>	3.1	3.7	4.3	3.4	3.3	4.2	5.8	3.2	2.5	4.0	3.1	2.0
TiO <sub>2</sub>	0.2	0.4	0.4	0.3	0.3	0.5	0.7	0.3	0.2	0.3	0.3	0.3
CaO	18.9	18.0	19.8	20.1	21.8	17.1	11.0	23.8	26.9	33.7	23.8	20.2
MgO	7.6	6.4	7.1	9.4	7.3	6.5	3.9	8.7	9.1	9.5	9.6	9.2
Na <sub>2</sub> O	2.9	1.9	1.5	4.9	2.0	1.4	1.5	2.9	3.4	3.6	2.8	2.5
K <sub>2</sub> O	12.9	10.0	12.2	12.4	10.2	9.8	6.8	11.3	6.7	4.5	11.3	16.9
Mn <sub>3</sub> O <sub>4</sub>	5.2	1.5	1.6	1.9	2.6	1.6	1.4	2.7	2.4	3.5	2.1	1.8
P <sub>2</sub> O <sub>5</sub>	7.1	4.2	5.1	5.2	5.3	4.9	2.7	5.9	5.9	5.9	4.8	5.4
SO <sub>3</sub>	4.4	2.9	3.3	10.2	3.8	2.9	1.1	3.3	2.6	4.4	2.6	2.1
<b>Composition % m/m As Analysed</b>												

Elemental Oxide	Sample Reference											
	2BR 1	2BR 2	2BR 3	2BR 4	2NBR 1	2NBR 2	2NBR 3	2NBR 4	2 RS 1	2 RS 2	2 RS 3	2 RS 4
SiO <sub>2</sub>	42.5	42.8	50.4	50.3	29.2	32.4	27.0	34.7	25.5	27.5	28.2	25.0
Al <sub>2</sub> O <sub>3</sub>	9.8	9.7	14.1	12.6	5.4	4.0	5.0	6.3	4.6	7.8	6.1	4.6
Fe <sub>2</sub> O <sub>3</sub>	4.1	4.1	5.9	5.1	2.9	2.7	3.2	3.4	2.5	4.0	3.4	2.5
TiO <sub>2</sub>	0.5	0.4	0.6	0.6	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.3
CaO	17.4	13.1	7.9	9.7	26.4	22.8	28.2	23.3	27.3	25.4	20.5	28.6
MgO	5.9	5.0	4.6	4.6	6.7	6.7	6.7	5.5	9.6	8.1	6.7	8.8
Na <sub>2</sub> O	2.3	1.6	1.5	1.8	1.5	2.3	1.6	2.3	2.3	1.8	2.0	1.8
K <sub>2</sub> O	9.9	11.5	8.3	8.0	12.3	12.5	14.0	13.2	6.6	3.9	7.0	8.2
Mn <sub>3</sub> O <sub>4</sub>	1.4	2.8	0.9	1.0	2.3	2.4	2.1	2.3	2.1	2.0	2.2	2.6
P <sub>2</sub> O <sub>5</sub>	5.1	5.1	2.8	3.3	6.9	7.9	7.7	6.9	5.9	4.0	5.8	6.3
SO <sub>3</sub>	2.8	2.8	2.0	3.2	4.2	4.5	4.0	4.4	14.8	13.2	13.4	13.6
<b>Composition % m/m As Analysed</b>												

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RELATIVE PROPORTIONS OF MAJOR ELEMENTS

Figure 1, below, shows the proportion of each of the major elements measured in the ash produced from burning the original chip samples, averaged for each treatment. The results are expressed as a percentage of a sample of ash, so they do not reflect the proportion of that element in the original chip sample, as the amount of ash produced varied.

Figure 1 Relative percentages of major elements in ash for each treatment

