INL/EXT-15-36368
Revision 0

Assessing Pinyon-Juniper Feedstock Properties and Utilization Options

WFO Project #11709

August 2015

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

Introduction

Pinyon-juniper woodlands are a major ecosystem type found in the Southwest and the Intermountain West regions of the United States. These ecosystems are characterized by the presence of several different species of pinyon, pine and juniper as the dominant plant cover. Since the 1800s, pinyon-juniper woodlands have rapidly expanded their range at the expense of existing ecosystems. Additionally, existing woodlands have become more dense, potentially increasing fire hazards. Land managers responsible for these areas often desire to reduce pinyon-juniper coverage on their lands for a variety of reasons, including restoration to previous vegetative cover, mitigation of fire risk, and improvement in wildlife habitat. However, the cost of clearing or thinning pinyon-juniper stands can be prohibitive. One reason for this is the lack of utilization options for the resulting biomass that could help recover some of the cost of pinyon-juniper stand management. The goal of this project was to assess the feedstock characteristics of biomass from a pinyon-juniper harvest so that potential applications for the biomass may be evaluated.

The overall pinyon-juniper harvest and utilization project was to test three alternative harvesting systems to examine cost, ecological impacts, and feedstock properties. The three systems represent distinctly different operating methods that affect all of these attributes. System 1 is a mulch-and-bale system that cuts and collects all material above 1-inch in height. The chopped biomass is compacted into round bales resembling agricultural hay bales. System 2 is a chip-and-forward system that travels into the stand, picks up felled material at the stump, and chips it into a collection trailer. Full trailers are pulled to roadside and dumped into highway transports or into piles. System 3 is a forward-and-chip system that travels into the stand, collects felled material into a compacting bunk, and forwards the whole material to the roadside. The material is then chipped using a conventional large-capacity chipper. The objective of this specific sub-component of the overall project to be conducted by the Idaho National Laboratory (INL) is to assess feedstock properties and potential densification of pinyon-juniper biomass in order to support a comparison of the three harvest systems.

Samples from the mulch-and-bale system (see Figure 1) were provided to INL for characterization. However, biomass from the other two systems was never received at INL, and it is our understanding that the harvests using those two systems were never completed by the U.S. Forest Service contractor. Therefore, characterization was only performed on biomass from one harvesting system. In the absence of samples from different harvesting systems, a comparison of pinyon-juniper was made with other woody biomass materials that include lodgepole pine, ponderosa pine, and hybrid poplar.

Upon receipt of the pinyon-juniper bales, they were fed into grinders within the Biomass Feedstock Process Demonstration Unit (PDU) at INL. The bales were initially fed into the Vermeer BG 480 bale grinder with 1-inch screen, and then dried in the rotary drier prior to final comminution using the Bliss hammermill with the 3/16-inch screen. The ground biomass was then characterized to determine its moisture content, particle size distribution, ash content, bulk density, and its fuel properties (proximate, ultimate, and calorimetric analysis) as needed. A sample of ground pinyon-juniper biomass was pelleted in a flat-die pellet mill in a process described in detail in a 2014 journal publication by Jaya Tumuluru [Tumuluru, J. S. *Biosystems Engineering* **2014**, 119, 44], and the density and durability of the pellets measured.

Figure 1: Pinyon-juniper mulch and bale harvesting system.

Grinding of Pinyon-Juniper Bales

Prior to grinding, the mass and the moisture content of the pinyon-juniper bales was determined (Table 1). Five bales were fed into a Vermeer BG 480 bale grinder fitted with a 1-inch screen. The BG 480 is composed of two grinding drums with swinging hammers powered by a 200-hp electric motor for each drum. Each bale was placed on the infeed conveyor with a different axial orientation to determine which orientation was optimal for processing (Figure 2). For the purposes of this report, the main axis of the cylindrical bales is considered to be the imaginary line connecting the center of the two circles on either end of the cylinder. For bale #1, the main axis of the bale was oriented vertically with respect to the infeed conveyor belt. The main axis for bale #2 was horizontal to the infeed conveyor belt and parallel to the feed direction. The main axis for bales #3 and #5 was also horizontal to the conveyor belt but perpendicular to the infeed direction. Bale #4 was placed onto the conveyor as a loose material pile. The length of time it took the grinder to process each bale and the measured power consumption is shown in Table 1 for bales 1 – 4. The data presented are from only one bale each and some amount of variation should be expected if more bales were processed. Therefore, these values should only be interpreted as an estimate of the duration of grinding and power consumption for future bales. Conclusions as to which bale orientation may be best should not be drawn without further research. Based upon qualitative observations recorded by the grinder operator, however, the orientation of bales #3 and #5 was the best for ease of feeding into the grinder.

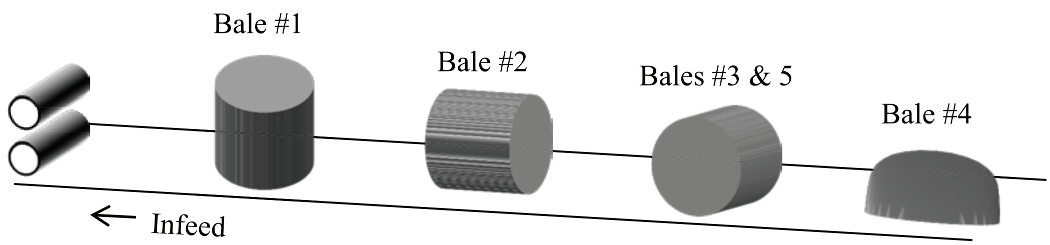

Figure 2: Orientation of bales fed into the Vermeer BG 480.

Table 1: Mass and moisture content of bales; duration and power consumption of primary grinding with the Vermeer BG 480.

Bale #	Mass (lbs)	Moisture Content (%)	Duration (min)	Power Consumption (kWh/OD ton)
1	810	14	14.1	25.9
2	836	18	19.0	40.2
3	832	14	17.0	29.2
4	580	15	12.5	33.4
5	876	15	--	--

After primary grinding with the BG 480 was completed, the material was fed into a Bliss hammermill with a 3/16-inch screen installed. Since the material had been homogenized by the primary grinding step, little difference in the grinding parameters was expected between the different bales.

Particle Size Analysis

The particle size distribution of materials sampled from the outlet of both the primary and secondary grinders was evaluated by sieve analysis. Material from the Vermeer BG 480 primary grinder was analyzed on a sieve shaker with sieve screen openings of 19 mm, 6.35 mm, 3.35 mm, 2.36 mm, 0.60 mm, 0.425 mm, 0.30 mm, and 0 mm (pan). Material from the Bliss hammermill was analyzed on a sieve shaker with sieve screen openings of 2.00 mm, 1.18 mm, 0.60 mm, 0.425 mm, 0.30 mm, 0.25 mm, 0.212 mm, and 0 mm (pan). Materials were analyzed both before and after drying, except for samples coming from bale #1 after primary grinding, which were all dried prior to sieve analysis. The particle size distribution for the pinyon-juniper biomass after primary grinding is shown in Figure 3, and the cumulative particle sizes for the same samples are shown in Figure 4. (See Appendix A for tables containing the raw data for these figures.) The distribution of all the samples followed the same general trend, with a local maximum at 3.35 mm and a larger maximum at 0.6 mm, regardless of drying history or orientation of bales fed into the grinder. The large particle size shown for the undried material from bale #2 may be an outlier, especially since the dried material from bale #2 did not demonstrate the same characteristics. Particle size characteristics for all the ground biomass samples after secondary grinding through the Bliss hammermill were also very similar (Figures 5 and 6). (See Appendix B for tables containing the raw data for these figures.) Particle sizes larger than approximately 1 mm were effectively reduced by the hammermill. The size distribution still had a maximum at 0.6 mm. For each of the bales, grinding of the wet material generated between 1.7 and 3.3% more fines collected on the pan than collected from the dried material. (The lines on Figures 3, 4, 5, and 6 were added to help visually follow trends and not to signify continuity between screen opening dimensions.)

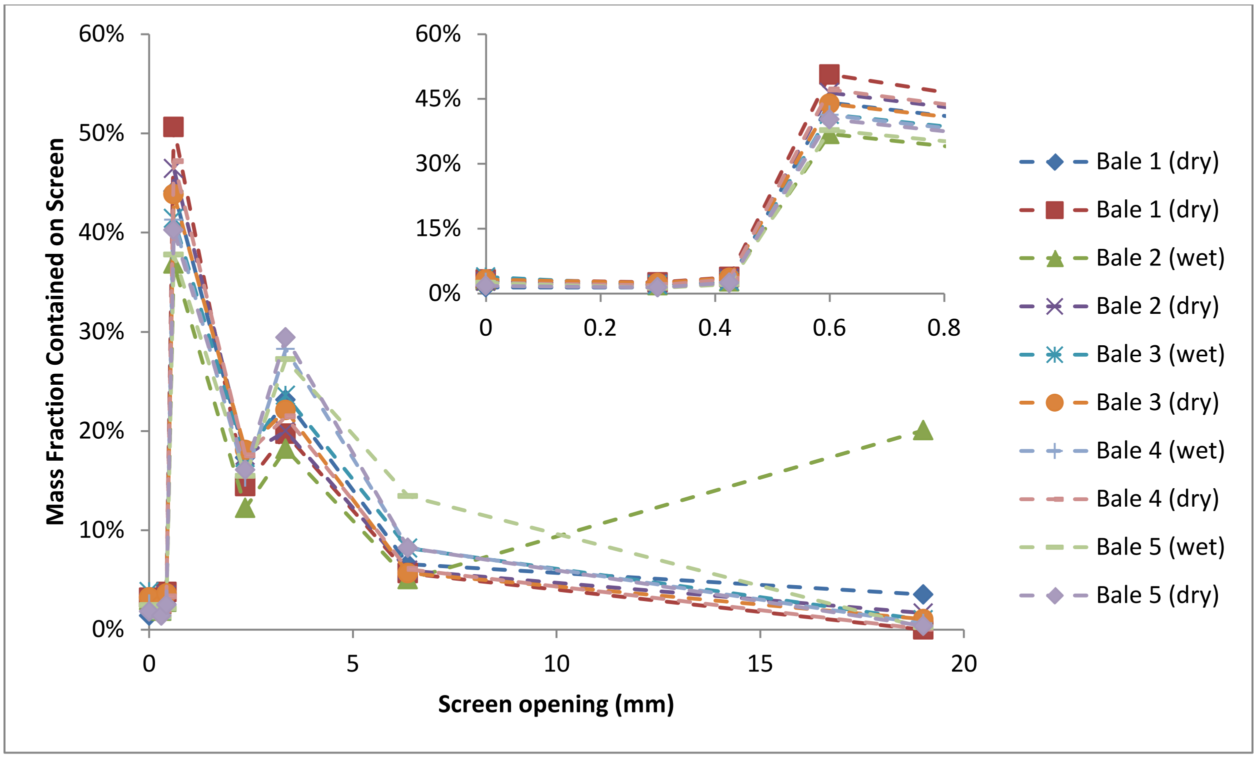

Figure 3: Particle size distribution by sieve analysis of pinyon-juniper biomass after primary grinding with a Vermeer BG 480 grinder with a 1-inch screen installed. (Inset shows an enlargement of the data at small screen openings.)

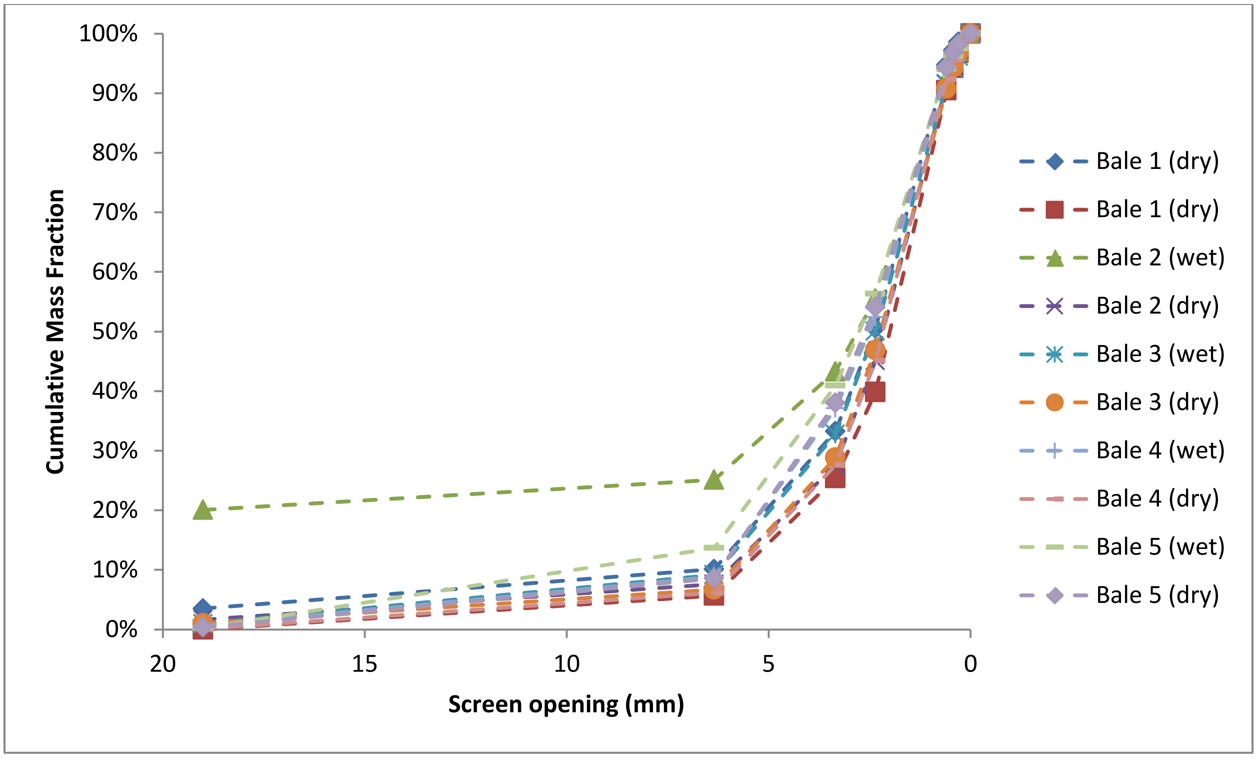

Figure 4: Cumulative particle sizes by sieve analysis of pinyon-juniper biomass after primary grinding with a Vermeer BG 480 grinder with a 1-inch screen installed.

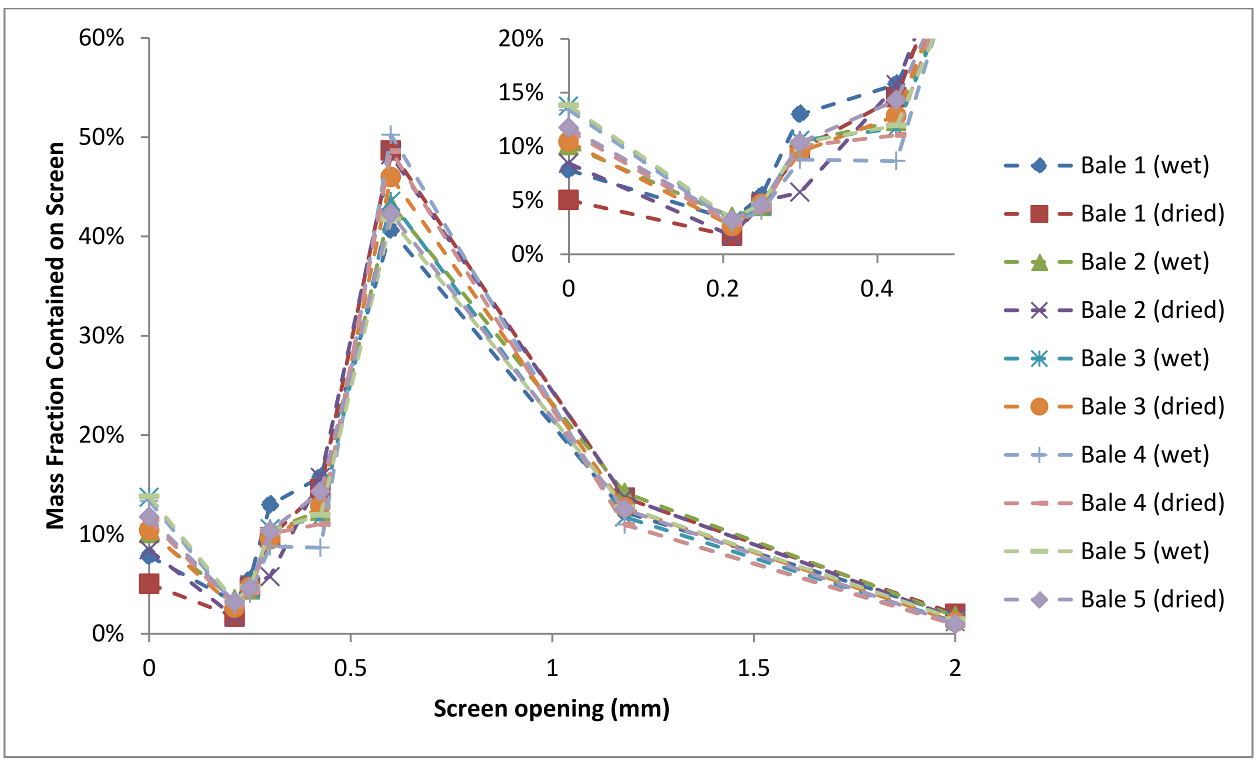

Figure 5: Particle size distribution by sieve analysis of pinyon-juniper biomass after secondary grinding with a Bliss hammermill with a 3/16-inch screen installed. (Inset shows an enlargement of the data at small screen openings.)

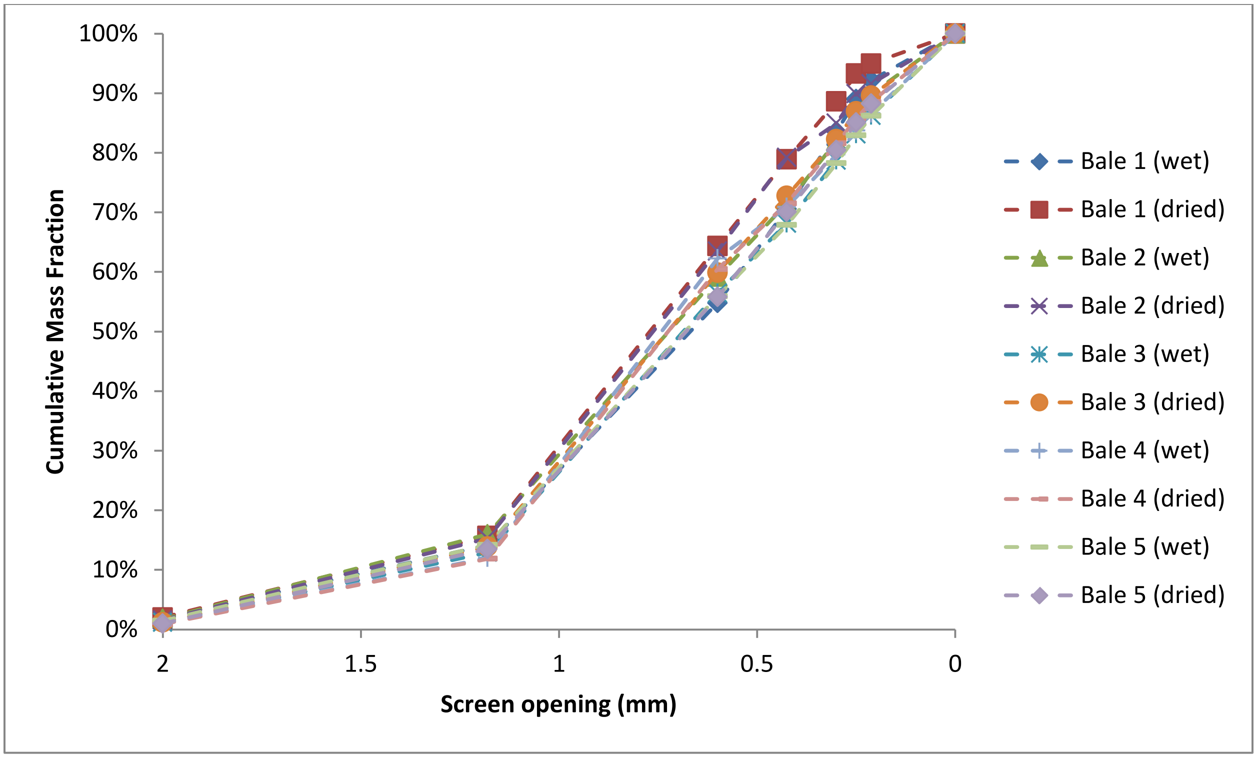

Figure 6: Cumulative particle sizes by sieve analysis of pinyon-juniper biomass after secondary grinding with a Bliss hammermill with a 3/16-inch screen installed.

<u>Ash Content of Different Particle Size Fractions</u>

The ash content of the particle size fractions retained on the screens with a 1.18-mm opening, 0.3-mm opening, and the pan were determined after sieve analysis for bales #1 - 3. These values are shown in Table 2. Ash analysis was performed according to NREL Laboratory Analytical Procedure: Determination of Ash in Biomass (NREL/TP-510-42622, January 2008). There is a clear trend in the ash content of the different particle sizes, with the smaller particle size fractions containing higher amounts of ash. This is a typical trend found in the analysis of biomass for the reason that the inorganic mineral content in biomass often occurs in smaller particles (fines) and is more brittle that the organic content of the biomass. One potential implication of this trend is that the ash content of the pinyon-juniper biomass can be significantly reduced by sieving or air fractionation to remove the fines after the grinding process.

Table 2: Ash content of pinyon-juniper particle size fractions retained on screens during particle sieving after grinding with a Bliss hammermill with a 3/16-inch screen installed.

Screen Opening	Bale #1		Bale #2		Bale #3	
(mm)	wet	dry	wet	dry	wet	dry
1.18	2.31%	2.36%	1.57%	1.91%	1.73%	2.87%
0.3	3.74%	3.81%	3.64%	4.75%	3.30%	4.71%
pan	6.93%	5.63%	14.04%	9.81%	16.96%	13.57%

Proximate, Ultimate, and Calorimetric Analysis of Ground Pinyon-Juniper

Values obtained from proximate, ultimate, and calorimetric analysis of the pinyon-juniper biomass that had been ground using the Bliss hammermill with the 3/16-inch screen installed are shown in Tables 3 and 4. Proximate analysis was performed according to ASTM D3172-07. Ultimate analysis was performed according to ASTM D3176-09 and ASTM D4239-10. Calorimetric content was determined by ASTM D5865-10. All reported values were determined by averaging the data obtained from triplicate samples, with the exception of the proximate data reported for bale #2 in Table 3, which was calculated from duplicate samples as a result of a sampling error. This may explain the higher error reported for the volatile and fixed carbon content of that sample compared to the others.

The proximate analysis in Table 3 reveals notable variability in the measured ash content between the bales. It is not uncommon to encounter variability in the ash content between bales of biomass, which likely arises from both the inherent variability of the ash in the biomass itself and from the introduced variability in the harvesting method. In this case, bale #4 had the most ash measured at 7.85%, and bale #1 had the least ash measured at 2.36%. These values of ash are markedly higher than what is observed for clean chipped hybrid poplar, debarked lodgepole pine or ponderosa pine at 1.24% ± 0.12 (n = 19), 0.40% ± 0.04 (n = 3), and 0.61% ± 0.26 (n = 2), respectively.

Hybrid poplar, lodgepole pine, and ponderosa pine characterization data was obtained and included in this study for comparative purposes. The increased ash content is most likely due to the inclusion of the bark, limbs, and needles in the bales, which typically has the highest ash concentration due to intrinsic elemental content and secondary soil inclusion. The %Volatiles content was lower for each of the bales tested and % Fixed Carbon content of the bales was marginally higher. Higher heating value (HHV) for the pinyon-juniper bales ranged from 8306.1 ± 116.4 to 8762.5 ± 135.6 and lower heating value (LHV) ranged from 6997.2 ± 116.4 to 7264.6 ± 84.6. These lower value ranges are representative of the increased ash content observed in the pinyon-juniper bales relative to the observed values for the exemplar hybrid poplar, lodgepole pine and ponderosa pine samples. Overall, the HHV, LHV, and volatiles content for the biomass samples decreased as the ash content increased.

Values for the ultimate analysis shown in Table 4 are reasonably consistent between each of the bales. Each pinyon-juniper sample contained approximately 50% elemental carbon by mass and was consistent with the observed values for the exemplar woody materials. The observed %Carbon for the exemplar hybrid poplar, lodgepole pine, and ponderosa pine samples was 49.99 ± 0.23, 52.06 ± 0.09 and 52.50 ± 0.90, respectively. The %Hydrogen content for the pinyon-juniper samples contained approximately 5.9% hydrogen, which is consistent with the 6.0% observed values for the exemplar woody materials. Only trace amounts of sulfur were observed in the pinyon-juniper samples, which is consistent with the observed values for the exemplar woody materials, averaging only 0.016%. Oxygen content was slightly lower for the pinyon-juniper bales, which averaged 38.71%, whereas the exemplar woody materials averaged 41.72%.

Table 3: Proximate and calorimetric values for the pinyon-juniper biomass after grinding with a Bliss hammermill with a 3/16-inch screen installed. All values reported on oven dry basis.

	% Volatile	% Ash	% Fixed Carbon	HHV (BTU/lb)	LLV (BTU/lb)
Bale #1	79.76 ± 0.39 [a]	2.36 ± 0.10 [a]	17.88 ± 0.45 [a]	8762.5 ± 135.6	7378.1 ± 135.6
Bale #2	80.50 ± 1.62 [b]	3.13 ± 0.01 [b]	16.38 ± 1.61 [b]	8646.7± 84.6	7264.6 ± 84.6
Bale #3	80.07 ± 0.24 [a]	3.71 ± 0.01 [a]	16.22 ± 0.24 [a]	8506.6 ± 152.9	7177.3 ± 152.9
Bale #4	75.61 ± 0.23 [a]	7.85 ± 0.18 [a]	16.55 ± 0.24 [a]	8306.1 ± 116.4	6997.2 ± 116.4
Bale #5	78.44 ± 0.50 [a]	4.86 ± 0.11 [a]	16.70 ± 0.50 [a]	8471.3 ± 113.2	7133.7 ± 113.2
Hybrid Poplar[c]	83.97 ± 0.61	1.24 ± 0.12	14.79 ± 0.61	8702.2 ± 121.8	7297.7 ± 75.3
Lodgepole pine[a]	86.02 ± 0.30	0.40 ± 0.04	13.57 ± 0.27	8804.4 ± 11.4	7394.7 ± 75.29
Ponderosa pine[b]	86.36 ± 0.24	0.61 ± 0..26	13.03 ± 0.26	8713.3 ± 503.4	7255.1 ± 488.2

a. n = 3
b. n = 2
c. n = 19

Table 4: Ultimate analysis values for the pinyon-juniper biomass bales after grinding with a Bliss hammermill with a 3/16-inch screen installed. All values reported on oven dry basis.

	% Hydrogen	% Carbon	% Nitrogen	% Oxygen	% Sulfur
Bale #1	5.98 ± 0.03	51.90 ± 0.17	0.00 ± 0.03	39.77 ± 0.19	0.036 ± 0.001
Bale #2	6.00 ± 0.05	51.75 ± 0.10	0.00 ± 0.02	39.15 ± 0.16	0.036 ± 0.000
Bale #3	5.80 ± 0.10	51.06 ± 0.04	0.23 ± 0.25	39.17 ± 0.14	0.035 ± 0.003
Bale #4	5.76 ± 0.01	49.31 ± 0.10	0.08 ± 0.05	36.95 ± 0.16	0.046 ± 0.001
Bale #5	5.84 ± 0.02	50.78 ± 0.17	0.00 ± 0.01	38.52 ± 0.18	0.039 ± 0.001

Bulk Density of Ground Pinyon-Juniper

The loose and tapped bulk density values for the pinyon-juniper biomass after having been ground through the Bliss hammermill with a 3/16-inch screen are shown in Table 5. The density values were determined according to ASTM D6393-08. The tapped bulk density presents a measure of the density that would be expected after material handling had caused the particles to settle. There is some variation in the data shown, with loose bulk densities ranging from 187 to 238 kg/m^3, and tapped bulk densities ranging from 219 to 280 kg/m^3. There is no apparent correlation between the bulk density values and the quantity of fines determined by the particle size analysis reported above.

Table 5: Loose and tapped bulk densities pinyon-juniper biomass after grinding with a Bliss hammermill with a 3/16-inch screen installed. The moisture content for the tested materials was between 2.3 and 3.4%.

	Bale #1	Bale #2	Bale #3	Bale #4	Bale #5
Loose (kg/m^3)	238	187	194	231	207
Tapped (kg/m^3)	272	219	229	280	247

Characteristics of Pelleted Pinyon-Juniper

A sample of ground pinyon-juniper biomass was pelleted in a flat-die pellet mill as described previously [Tumuluru, J. S. *Biosystems Engineering* **2014**, 119, 44]. The pellets were pressed under high-moisture conditions, with the moisture content of the feed material adjusted to 33%. The moisture content, density, and durability values for the resulting pellets are shown in Table 6. These values were determined according to methods described above and detailed in the publication by Tumuluru et al., [Tumuluru, J. S. *Applied Engineering in Agriculture*, 2010 26(6), 1013]. For comparative purposes, exported pellets made for heat and power production from saw mill residue (soft wood species of spruce, pine, and Douglas fir), with no content to bark or additives as described in the above publication, had moisture contents that ranged from 3.5 to 6.5%, unit bulk density from 1126 to 1191 kg/m^3, loose bulk density from 728 to 808 kg/m^3, and durability from 97 to 99%. The durability of the pellets compares favorably to the durability of pellets from this study; although, the unit and bulk densities of pinyon-juniper pellets were notably less. Also of note, the ash content of the exported pellets ranged from 0.26 to 0.93%; these results are consistent with the lodgepole pine and ponderosa pine ash results previously discussed.

Table 6: Characteristics of pinyon-juniper biomass pellets pressed under high moisture conditions.

Pellet Moisture Content	< 9.0%
Unit Density	974 kg/m^3
Bulk Density, loose	539 kg/m^3
Bulk Density, tapped	598 kg/m^3
Durability	98.24%

Conclusion

The initial moisture content of the pinyon-juniper bales ranged from 14 to 18%. Proximate analysis revealed lower %Volatiles for each of the bales tested and % Fixed Carbon content was marginally higher relative to clean chipped hybrid poplar, debarked lodgepole pine, or ponderosa pine exemplars. The respective HHV and LHV are representative of the increase in ash content observed in the pinyon-juniper bales. Values for %Elemental carbon, %Hydrogen content, and %Sulfur content were reasonably consistent between each of the bales relative to the exemplar woody materials, with %Oxygen content slightly lower for the pinyon-juniper bales. The durability of the pellets compares favorably to the durability of pellets from the Tululuru study; however, the unit bulk density of pinyon-juniper pellets was notably less.

Results revealed notable variability in the measured ash content between the bales, ranging from 2.36 - 7.85 weight percent. The variability of the ash content is most likely due to the harvesting method and the introduction of soil [Kenney, K. L., Smith, W. A., Gresham, G. L. and Westover, T. L. *Special Focus Issue; Advanced Feedstocks for Advanced Biofuels, Biofuels* **2012**, 4 (1): 111-127]. Elevated ash contents could be due to the intrinsic physiological ash, primarily trapped in the bark, but the research indicates soil inclusion due the harvesting method is the most likely entrainment method. Additional testing is needed to differentiate the sources of ash (physiological vs heart wood vs introduced), as well as, the elemental speciation of the ash, which can impact downstream conversion processes. Ash components impair catalysts and contribute to slag formation within the combustion processes; ash specification for thermochemical conversion is typically 1% or less. Ash content of the pinyon-juniper biomass can be reduced by sieving or air fractionation during preprocessing to remove the fines during the grinding process, but preventing inclusion of ash at the onset may be the most economical.

Appendix A: Sieve analysis data for pinyon-juniper biomass after primary grinding with a Vermeer BG 480 grinder with a 1 inch screen installed.

Bale 1 (dry)
Barcode: 49cfadb1-d227-2c48-b802-8510f7adf7b4

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	9.65	3.51%	3.51%
0.25	6.35	18.09	6.59%	10.10%
0.132	3.35	63.55	23.15%	33.25%
0.0937	2.36	47.53	17.31%	50.56%
0.0234	0.6	121.22	44.15%	94.72%
0.0165	0.425	6.8	2.48%	97.20%
0.0117	0.3	3.89	1.42%	98.61%
pan	0	3.81	1.39%	100.00%

Bale 1 (dry)
Barcode: eb2c2cbf-154e-fb4e-ab40-4c237aed434c

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	--	--	--
0.25	6.35	11.37	5.67%	5.67%
0.132	3.35	39.57	19.73%	25.40%
0.0937	2.36	28.96	14.44%	39.84%
0.0234	0.6	101.54	50.64%	90.48%
0.0165	0.425	7.54	3.76%	94.24%
0.0117	0.3	5.13	2.56%	96.80%
pan	0	6.42	3.20%	100.00%

Bale 2 (wet)
Barcode: 15ac66dd-03eb-d44c-9f00-83ff02324c31

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	62.84	20.06%	20.06%
0.25	6.35	15.83	5.05%	25.12%
0.132	3.35	56.99	18.20%	43.31%
0.0937	2.36	38.34	12.24%	55.55%
0.0234	0.6	115.44	36.86%	92.41%
0.0165	0.425	8.68	2.77%	95.18%
0.0117	0.3	5.81	1.85%	97.04%
pan	0	9.28	2.96%	100.00%

Bale 2 (dry)
Barcode: 8527cd4e-e196-e24a-8c5b-1b590a3255ec

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	3.77	1.65%	1.65%
0.25	6.35	13.6	5.95%	7.60%
0.132	3.35	45.71	20.00%	27.59%
0.0937	2.36	40.09	17.54%	45.13%
0.0234	0.6	106.16	46.44%	91.57%
0.0165	0.425	7.91	3.46%	95.03%
0.0117	0.3	5.06	2.21%	97.24%
pan	0	6.3	2.76%	100.00%

Bale 3 (wet)
Barcode: 0c1b31c4-5de7-8d4b-a45e-2300ce5660c3

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	3.36	0.98%	0.98%
0.25	6.35	28.09	8.19%	9.17%
0.132	3.35	80.87	23.59%	32.76%
0.0937	2.36	59.34	17.31%	50.07%
0.0234	0.6	141.92	41.39%	91.46%
0.0165	0.425	9.65	2.81%	94.27%
0.0117	0.3	6.56	1.91%	96.19%
pan	0	13.08	3.81%	100.00%

Bale 3 (dry)
Barcode: 2de15cd8-9e89-2844-beaf-9f3b0f619129

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	2.81	1.04%	1.04%
0.25	6.35	15.36	5.68%	6.71%
0.132	3.35	59.86	22.12%	28.83%
0.0937	2.36	48.89	18.07%	46.90%
0.0234	0.6	118.7	43.86%	90.76%
0.0165	0.425	9.74	3.60%	94.36%
0.0117	0.3	6.54	2.42%	96.77%
pan	0	8.73	3.23%	100.00%

Bale 4 (wet)
Barcode: e7788e0e-064a-b24a-a5d6-907522f0b6d2

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	2.4	0.61%	0.61%
0.25	6.35	32.65	8.25%	8.86%
0.132	3.35	111.73	28.25%	37.11%
0.0937	2.36	60.57	15.31%	52.42%
0.0234	0.6	163.24	41.27%	93.69%
0.0165	0.425	9.23	2.33%	96.02%
0.0117	0.3	5.49	1.39%	97.41%
pan	0	2.4	0.61%	0.61%

Bale 4 (dry)
Barcode: 1c221b12-7017-4a49-83d5-d54a66c8a28b

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	0.18	0.06%	0.06%
0.25	6.35	18.52	6.08%	6.14%
0.132	3.35	65.35	21.46%	27.59%
0.0937	2.36	53.44	17.54%	45.14%
0.0234	0.6	143.66	47.17%	92.30%
0.0165	0.425	10.1	3.32%	95.62%
0.0117	0.3	5.87	1.93%	97.55%
pan	0	7.47	2.45%	100.00%

Bale 5 (wet)
Barcode: 90ee88a0-8e79-ca4c-b69c-507298edfc98

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	0.81	0.22%	0.22%
0.25	6.35	48.6	13.45%	13.67%
0.132	3.35	98.4	27.23%	40.90%
0.0937	2.36	55.87	15.46%	56.36%
0.0234	0.6	136.51	37.77%	94.13%
0.0165	0.425	7.69	2.13%	96.26%
0.0117	0.3	4.66	1.29%	97.55%
pan	0	8.85	2.45%	100.00%

Bale 5 (dry)
Barcode: 3bc3afcd-1729-634f-b206-53012826091b

Screen (in)	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
0.75	19	1.15	0.36%	0.36%
0.25	6.35	25.96	8.23%	8.59%
0.132	3.35	92.84	29.42%	38.01%
0.0937	2.36	50.75	16.08%	54.10%
0.0234	0.6	127.03	40.26%	94.35%
0.0165	0.425	7.79	2.47%	96.82%
0.0117	0.3	4.38	1.39%	98.21%
pan	0	5.65	1.79%	100.00%

Appendix B: Sieve analysis data for pinyon-juniper biomass after secondary grinding with a Bliss hammermill with a 3/16 inch screen installed.

Bale 1 (wet)
Barcode: 647f4a54-6792-b847-8b94-0472771f61c9

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	8.96	1.90%	1.90%
16 mesh	1.18	57.83	12.23%	14.13%
30 mesh	0.6	192.23	40.66%	54.79%
40 mesh	0.425	74.57	15.77%	70.56%
50 mesh	0.3	61.39	12.99%	83.55%
60 mesh	0.25	25.71	5.44%	88.98%
70 mesh	0.212	15.09	3.19%	92.18%
pan	0	36.99	7.82%	100.00%

Bale 1 (dry)
Barcode: dba1bbd4-0766-f647-bfce-acaad4781834

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	9.75	1.99%	1.99%
16 mesh	1.18	67.05	13.69%	15.68%
30 mesh	0.6	238.34	48.66%	64.34%
40 mesh	0.425	71.29	14.55%	78.89%
50 mesh	0.3	47.52	9.70%	88.60%
60 mesh	0.25	22.87	4.67%	93.26%
70 mesh	0.212	8.37	1.71%	94.97%
pan	0	24.62	5.03%	100.00%

Bale 2 (wet)
Barcode: fd586f43-ed1f-704d-aa3f-095153e8998c

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	8.53	1.77%	1.77%
16 mesh	1.18	68.38	14.18%	15.95%
30 mesh	0.6	208.34	43.21%	59.17%
40 mesh	0.425	59.6	12.36%	71.53%
50 mesh	0.3	50.22	10.42%	81.95%
60 mesh	0.25	21.51	4.46%	86.41%
70 mesh	0.212	16.7	3.46%	89.87%
pan	0	48.83	10.13%	100.00%

Bale 2 (dry)
Barcode: fccd180d-58f0-e940-9d45-57360a077c5a

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	6.53	1.56%	1.56%
16 mesh	1.18	57.5	13.73%	15.29%
30 mesh	0.6	201.84	48.20%	63.49%
40 mesh	0.425	65.79	15.71%	79.21%
50 mesh	0.3	24.06	5.75%	84.95%
60 mesh	0.25	20.64	4.93%	89.88%
70 mesh	0.212	7.08	1.69%	91.57%
pan	0	35.29	8.43%	100.00%

Bale 3 (wet)
Barcode: aebdc616-516f-9143-8f43-87abfcca7d99

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	6.29	1.19%	1.19%
16 mesh	1.18	62.05	11.74%	12.93%
30 mesh	0.6	230.13	43.54%	56.47%
40 mesh	0.425	61.88	11.71%	68.17%
50 mesh	0.3	55.8	10.56%	78.73%
60 mesh	0.25	23.37	4.42%	83.15%
70 mesh	0.212	16.44	3.11%	86.26%
pan	0	72.62	13.74%	100.00%

Bale 3 (dry)
Barcode: a3e6bc6f-ad80-a24d-8678-67013f4b4f38

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	4.96	1.19%	1.19%
16 mesh	1.18	53.13	12.72%	13.90%
30 mesh	0.6	192.14	45.99%	59.89%
40 mesh	0.425	53.72	12.86%	72.75%
50 mesh	0.3	39.75	9.51%	82.26%
60 mesh	0.25	19.6	4.69%	86.95%
70 mesh	0.212	10.91	2.61%	89.56%
pan	0	43.6	10.44%	100.00%

Bale 4 (wet)
Barcode: ad04e514-7786-5b43-81d6-429c9c885678

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	6.37	1.03%	1.03%
16 mesh	1.18	67.83	10.98%	12.01%
30 mesh	0.6	310.4	50.23%	62.24%
40 mesh	0.425	53.49	8.66%	70.90%
50 mesh	0.3	54.33	8.79%	79.69%
60 mesh	0.25	24.9	4.03%	83.72%
70 mesh	0.212	17.89	2.90%	86.62%
pan	0	82.69	13.38%	100.00%

Bale 4 (dry)
Barcode: 01967cc5-4202-7349-b0dd-96f6d2c55620

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	4.34	0.89%	0.89%
16 mesh	1.18	53.66	10.96%	11.85%
30 mesh	0.6	237.84	48.60%	60.45%
40 mesh	0.425	54.08	11.05%	71.50%
50 mesh	0.3	49.21	10.06%	81.56%
60 mesh	0.25	20.56	4.20%	85.76%
70 mesh	0.212	13.55	2.77%	88.53%
pan	0	56.14	11.47%	100.00%

Bale 5 (wet)
Barcode: 8d8b6410-ad8e-f645-8ca6-3592d71a6ed6

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	7.37	1.45%	1.45%
16 mesh	1.18	64.54	12.73%	14.19%
30 mesh	0.6	211.46	41.72%	55.91%
40 mesh	0.425	60.59	11.95%	67.86%
50 mesh	0.3	52.62	10.38%	78.24%
60 mesh	0.25	23.65	4.67%	82.91%
70 mesh	0.212	16.57	3.27%	86.18%
pan	0	70.06	13.82%	100.00%

Bale 5 (dry)
Barcode: 9e47ae51-a216-e44e-91c1-2deb24d31863

Screen	Screen (mm)	Mass (g)	Mass fraction	Cumulative mass fraction
10 mesh	2	3.96	0.98%	0.98%
16 mesh	1.18	50.72	12.53%	13.50%
30 mesh	0.6	171.26	42.30%	55.80%
40 mesh	0.425	57.92	14.30%	70.11%
50 mesh	0.3	41.93	10.36%	80.46%
60 mesh	0.25	18.65	4.61%	85.07%
70 mesh	0.212	12.87	3.18%	88.25%
pan	0	47.59	11.75%	100.00%