2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 12-1337408

Beneficiation of Chipped and Shredded Woody Biomass

James H. Dooley, PhD, PE
Forest Concepts, LLC

David N. Lanning
Forest Concepts, LLC

Christopher J. Lanning
Forest Concepts, LLC

Written for presentation at the
2012 ASABE Annual International Meeting
Sponsored by ASABE
Hilton Anatole
Dallas, Texas
July 29 – August 1, 2012

Abstract. Forest Concepts, with funding from USDA NIFA SBIR program, developed methods and equipment to reprocess low-value dirty forest chips, tree service chips, and hog fuel into high value clean wood fiber and other valuable fractions. Traditional clean sources of mill residuals (sawdust, shavings, and chips) are declining rapidly due to improved sawmilling efficiencies and a general decline in the number of sawmills in operation. Thus, competition for low-cost clean fiber is intense. A USDA NIFA SBIR supported beneficiation project sought to increase the clean fiber supply by tapping low grade, often inexpensive or negative cost raw materials. To validate the SBIR funded engineering science work, our engineers designed and built a set of demonstration-scale (one ton per hour) machines that can be mixed and matched to clean low grade woody biomass to meet nearly any ash or bark content specification. Results of validation tests demonstrate the performance of innovative methods for cleaning high-ash land clearing debris.

Keywords. *biomass, bioenergy, forestry, feedstock, hog fuel, wood chips*

Introduction

Woody biomass is an increasing source of biofuel and bioenergy feedstock around the globe (Barfield, Clarke et al. 1992; Bailey, Dyer et al. 2011; Alex Marvin, Schmidt et al. 2012). Increased use of woody feedstocks is putting pressure on the price and availability of clean wood fiber for traditional uses in the manufacture of paper, composite panels and other building products. There is a critical need for new processing technologies that enable cleaning of low-grade woody biomass raw materials to meet the fiber quality requirements for traditional uses as well as the emerging demand from solid and liquid biofuel producers.

Tens of millions of tons of prunings, land clearing debris, logging slash, and urban greenwood are chipped or ground each year as a means of volume reduction for transport and/or disposal. Commingled chipped whole-plant materials have little value other than as compost, mulch and direct combustion energy. The core premise of the Forest Concepts development effort is that commingled woody biomass “chips” from the above sources contain economically significant amounts of bole and branch wood (aka white wood fiber). If most of the wood content can be separated and cleaned, then more clean wood fiber will be available in the marketplace, thus reducing the competition for pulp grade chips and tension between users of roundwood resources.

A second benefit of the beneficiation technology will be to second generation cellulosic biofuels producers. Separation of the bark and wood content of commingled woody biomass feedstocks may improve the yield of second generation transportation liquid fuel processes and improve the economics of producing both residential and industrial grade solid fuel pellets. Across all applications, the implementation of reprocessing technologies is likely to stimulate creation of new jobs and economic activity in timber dependent communities as well as in industrial neighborhoods of the urban centers.

The development project is guided by the following operational premises:

- Collection of fiber from non-traditional and new sources has the potential to significantly increase the total fiber supply.
- Clean wood fiber from reprocessed shredded and ground biomass is suitable for composite wood products, premium fuel pellets and other uses that traditionally were supplied with increasingly scarce forest products mill residuals, sawdust and planer shavings.
- Clean bark resulting from the process is high in energy content and low in grit.
- The remaining fines and dirt have value in the mulch, soil amendment, and other markets.

Safety Emphasis

Beneficiation, or cleaning of low-grade chipped and ground woody biomass, necessarily involves powered equipment having rotating components, pinch points, electric energy and other potential hazards. Laboratory and prototype equipment designed, built, and used in this development project were carefully designed and reviewed to minimize or mitigate known hazards. Wash water, when used as part of the cleaning process, is recycled through a novel organic media filter to minimize discharge. By processing materials wet, dust is minimized.

From Woody Biomass to Feedstock

In the context of this paper, the term woody biomass is meant to encompass logs, branches, prunings, land clearing debris, utility corridor trimmings and the like. None of these materials are directly suitable for use in the production of biopower, biofuels, or bioproducts. All need to be chipped or ground to appropriate particle sizes and cleaned to various extents prior to becoming a feedstock for value-added purposes.

A B C

Figure 1. Land clearing debris woody biomass (A), grinding biomass (B), and clean woody biomass feedstock from ground land clearing debris (C).

The quality specifications and value of woody biomass-derived feedstocks is determined by the effects of biomass physical properties (size, shape, moisture content) and chemical properties (ash composition, soluble mineral content). Ash content is a determining factor for solid biofuels such as wood pellets, torrefied bio-coal, and charcoal. Logging forest residuals and land clearing debris typically contain 10-20 percent ash, while industrial export pellets must have less than 3 percent ash and residential grade pellets must have less than 1 percent ash content. There is increasing evidence among those developing advanced liquid transportation fuels that minerals such as iron oxide, calcium carbonate, sulfur, magnesium, and potassium greatly reduce the yield of alcohols or pyrolysis oils, and thus are important targets during biomass cleaning.

Environmental ash in the form of sand, grit, stones, road dust and the like are also major causes of wear in conveyors, grinders, augers, and other processing equipment. In the case of composite panel bio-products, grit is to be avoided since it chips finishing cutters, routers and other woodworking tools.

The transformation of woody biomass to feedstocks involves appropriate processing through the following list of unit operations. Depending of the characteristics of the raw biomass and the specifications for an intended use, the precise mix of equipment and the processing order must be optimally determined.

- Comminution with grinders, chippers, shears, mills…
- Size sorting with screens, trommels…
- Anatomical fractionation to separate bark, wood, leaves, needles…
- Contaminant cleaning to remove soil, gravel, metal, grit, plastics…
- Washing to remove clays, silts, dust…
- Leaching to remove soluble minerals and extractives…

Comminution most often occurs in a sequence of steps through the supply chain. As noted in Figure 1, grinding in the field increases bulk density for transport. Subsequent milling after cleaning is often applied to produce the final particle size needed for a specific end use.

Size sorting early in the supply chain is often used to remove dirt and other high-ash fine materials, as well as to remove large chunks of wood or rock that may damage downstream processing equipment. Size sorting late in the supply chain, which may include specific gravity sorting, is applied to ensure that all feedstocks delivered to a user are within the acceptable size range.

Other processing unit operations may or may not be incorporated into a beneficiation system depending on the raw biomass characteristics and the end use specifications.

Methods and Materials

Forest Concepts conducted two rounds of woody biomass characterization and process development. The first round included collection of woody biomass samples from urban, suburban, forest, and industrial producers in Washington, Idaho, and Montana. The materials were characterized following Forest Concepts' protocols for sieve size, particle shape, anatomical content, moisture content, and total ash. These samples and data were used to define technical and functional specifications for biomass beneficiation equipment to reduce the ash and bark content.

A second round of samples were collected from western Washington at sites representing urban arborist chips, ground land clearing debris, and forest residual logging slash fuel chips. These samples were subjected to the same characterization as the earlier multi-state samples, plus were used in beneficiation process validation tests of prototype equipment.

A 10-20 kg representative sample of each bulk biomass was obtained by either sampling around a pile or drawing from bins. The Forest Concepts sample collection protocol is adapted from the EN/CEN standards for biomass sampling. The samples were piled on a smooth table top and divided into eight equal subsamples. Each subsample was bagged in a sealed poly bag and numbered. Six of the eight subsamples were subsequently used in analyses, with the bags being randomly chosen for each analysis.

Moisture content was evaluated using our drying ovens following the ASABE protocol (ASABE 2008). After oven drying, subsamples of the dried material was subjected to our ash protocol to determine ash content.

Particle size distribution was determined for two subsamples by sieving for ten minutes in a sieve stack using Ro-Tap® particle size analysis equipment. Each size fraction was then separated into anatomical and debris content following the Forest Concepts protocols.

A float/sink analysis that includes particle size and content after the sample was floated in an agitated bath was conducted for two sub-samples. The float and sink fractions were dried and evaluated.

Validation of the engineering science and research was assessed through the design, construction and testing of a "one ton per hour" prototype complete woody biomass beneficiation system. The prototype includes all equipment, conveyors and water handling devices.

Process and Equipment System Overview

We determined the process flow of a beneficiation system would be as shown below. Simplifying the steps, we:

1. Size sort to remove free grit, fines, soil and grossly oversize material
2. Process the keep fraction through wood/bark separation device
3. Remove resulting undersized fraction that should be mostly bark fragments
4. Wash retained wood fraction to remove remaining silt, grit and gravel
5. Dewater washed clean wood fraction and
6. Pass across a dewatering and polishing screen to air dry for storage and shipping

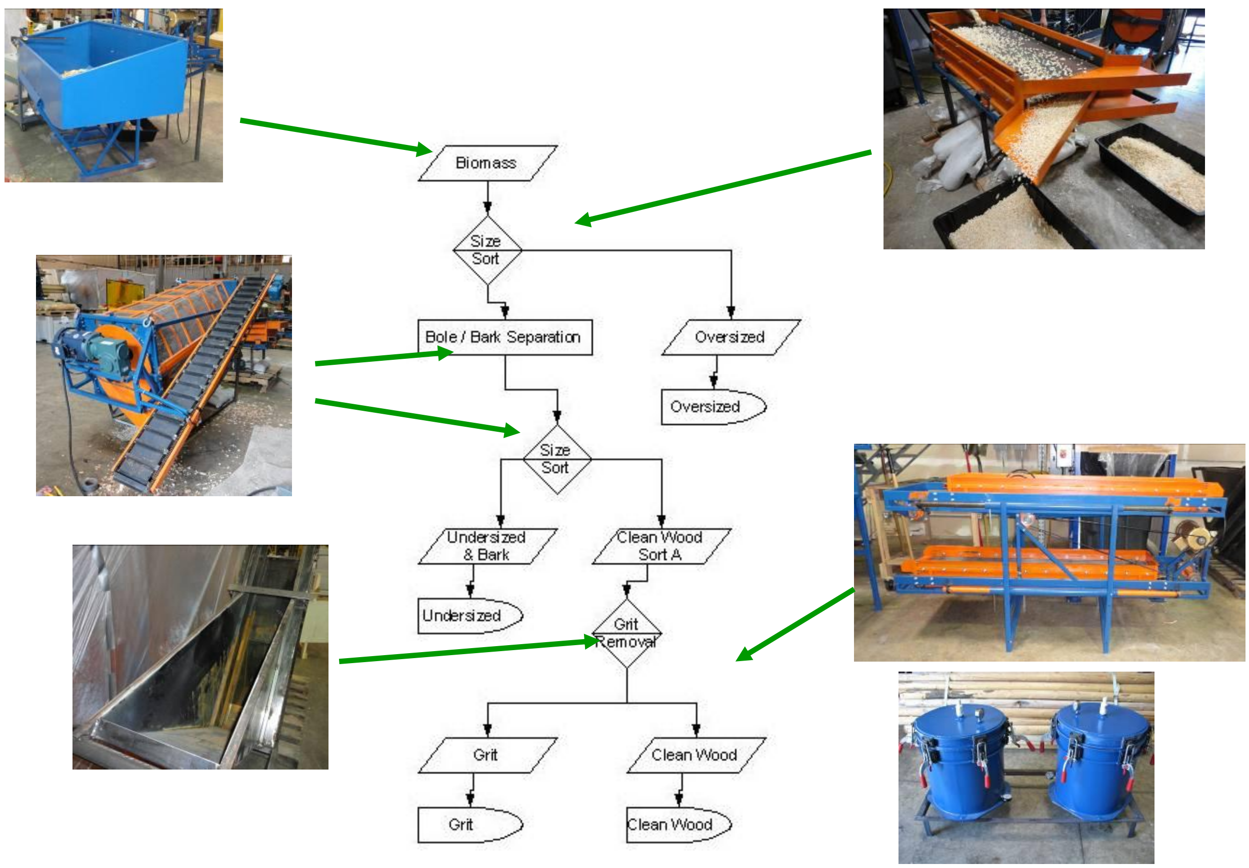

Figure 2. Process flow diagram of chip beneficiation system surrounded by July 2011 photos of the physical equipment.

Design of all prototype equipment was completed as SolidWorks® computer aided design models. Three dimensional solid models for each module machine were merged into the entire beneficiation system. Detailed drawing sets were prepared for each of the process modules, as well as for the electronic control module and water recycling system. The fabrication was done in-house with all machined components being made by a set of outside shops. Design and fabrication of the prototype equipment took approximately 10 months. As each modular machine was completed, it was tested independently of the whole system. After individual performance was judged acceptable, the system was gradually combined into an end-to-end process.The entire suite of equipment was integrated and sized such that it could be transported on a single trailer.

Results of Validation Experiments

Our validation experiments will be briefly described for each machine module and then a summary of system results will be presented. Validation tests were conducted on three common woody biomass raw materials collected from western Washington:

1. Fuel grade whole tree wood chips
2. Urban arborist tree service chips
3. Ground land clearing debris

Figure 3. Beneficiation process validation experiments were conducted with the three low-grade woody biomass materials shown from left to right – fuel grade wood chips, urban arborist chips, and ground land clearing debris.

The fuel grade wood chips were graciously provided by Hermann Brothers Logging of Port Angeles, WA. The chips are from the same equipment and forest materials used to produce fuel chips for Nippon Paper's cogeneration boiler in Port Angeles, WA. These chips are extremely clean and low bark content. We expected that our beneficiation process would reduce the bark content with minimal loss of clean fiber.

The urban arborist chips were from ponderosa pine cut and chipped by R&S Enterprises tree service firm in Sumner, WA. This material appeared to be mostly pine needles and small barky branches with minimal wood content. As will be seen in the characterization this material was only about 15 percent wood, well below what we would consider commercially viable to upgrade using our processes. However, this material presented an extreme challenge for our validation experiments at the opposite end of the spectrum from the Hermann Brothers fuel chips.

Ground land clearing debris was provided to us by Rainier Wood Recyclers in Covington, WA. Rainer Wood Recyclers processed the material using their Universal Refiner wood grinder and did not screen the material prior to providing it to us. Normally they would screen out the extreme overs for regrinding, and send all ¾-inch minus material to soil products. For our purposes, the raw unscreened material was used to provide a challenge to our materials handling processes.

In each case we were provided at no cost to us with approximately one ton of material which is the equivalent volume of about four pallet bins.

Raw Material Characterization

All three materials were subjected to Forest Concepts' biomass feedstock particle size and content analyses following protocols developed and published in 2008. Primary analyses include moisture content, particle size, anatomical content including grit and debris, and ash content.

The charts below are from one each of the raw materials characterized. Following the graphs, additional numerical detail is provided in table form for the raw material and the results of each validation experiment.

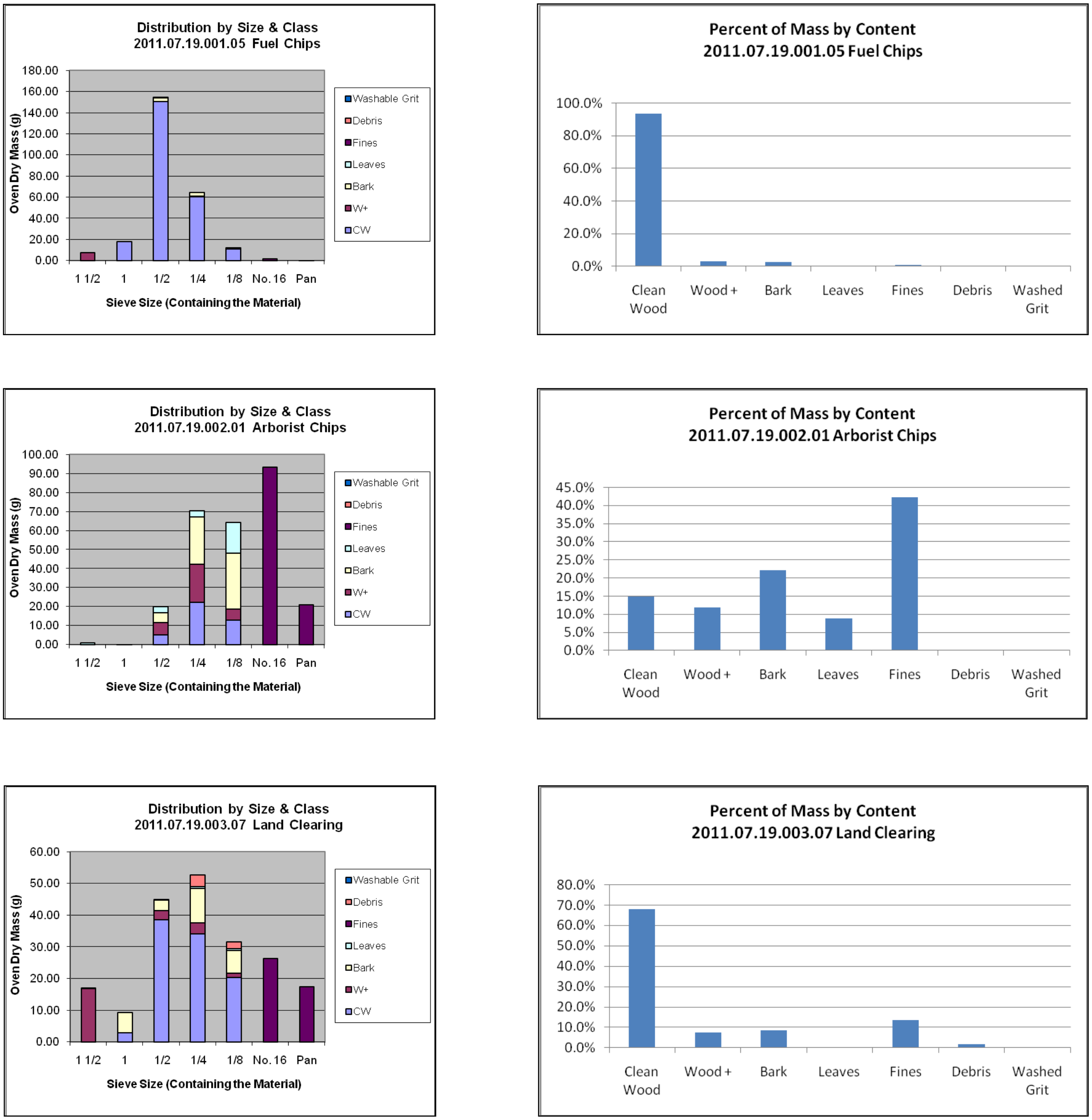

Figure 4. Content and particle sieve size characterizations from representative samples from each of the three raw materials for use in validation experiments.

It should be readily apparent from the above graphs that the three materials have vastly different anatomical content, including the amount of bole wood. We expected that each of the three would challenge our prototype beneficiation system in different ways. The fuel chips are already very clean, so making meaningful improvement would be difficult. The arborist chips start with less than 25 percent total wood content so the volume of debris that our system would have to handle as the non-wood content is removed would be challenging. Finally, the ground land clearing debris contains rocks, stones and dirt that must be removed without excessive loss of clean wood.

Table 1. Summary of raw material characteristics (average of two samples for each material. Standard deviations shown in brackets where appropriate.

	Fuel Chips	Arborist Chips	Land Clearing Debris
All Particle Sieve Size (mm) Geometric Mean Dimension	15.8 (2.4)	3.4 (3.6)	12.4 (5.9)
Wood Particle Sieve Size (mm) Geometric Mean Dimension	16.3 (2.2)	6.7 (3.7)	22.8 (4.8)
Moisture Content (% wb)	44	46	27
Ash Content (% dwb)	0.28	3.2	12.3
Clean Wood Content (% dwb)	92	17	68
Bark Content (% dwb)	4	18	11

The raw material was also subjected to a static washing characterization using a float tank. If we use a flotation separator to remove the rock and gravel, we expect that high specific gravity wood particles, mostly from knots, will sink and be lost from the potentially recoverable wood fraction.

Table 2. Summary of raw material characteristics after water flotation sorting

	Fuel Chips	Arborist Chips	Land Clearing Debris
All Particle Sieve Size (mm) Geometric Mean Dimension	18.2 (2.5)	3.6 (3.8)	9.7 (3.6)
Wood Particle Sieve Size (mm) Geometric Mean Dimension	18.8 (2.4)	7.4 (3.9)	11.3 (3.4)
Clean Wood Content (% dwb)	85	16	64
Bark Content (% dwb)	2.6	15	11
Sink Fraction (% dwb)	9.2	19	12

Approximately 100 kg of each raw material was first processed across the two deck primary screen. The top screen was 50 mm (2-inch) opening and the bottom screen was 6.4 mm (1/4-

inch) opening. The accept fraction was the material retained on top of the 6.4 mm screen. We expect that the primary screen will remove much of the fine sand, soil, and bark fines, resulting in a much lower ash content material. In the case of producing coal replacement fuels such as torrefied wood, we believe that screening may be sufficient to achieve the 6% ash specification for torrefied bio-coal.

Table 3. Summary of material characteristics after primary screening by two-deck screen (A-round)

	Fuel Chips	Arborist Chips	Land Clearing Debris
Ash Content (% dwb)	0.33	2.56	2.05
Percent of Mass in Accept Fraction of this process (Yield)	93	43	67

Comparison of the data in Table 3 with the raw materials shown in Table 2 shows that we improved the clean wood content on a percentage basis as expected for both the arborist chips and the land clearing debris. The fuel chips, which were originally of high quality, passed through this portion of the beneficiation system with little change.

The output of the two-deck primary screen was passed to the infeed of the debarker module. Two separate experiments were conducted with the debarker module, one where the material was processed dry and the other when the debarker was flooded by a water spray to further wash fines and dirt from the biomass material. The next two tables present the results for dry and wet debarking respectively.

Table 4. Summary of material characteristics after dry processing though Debarker Module

	Fuel Chips	Arborist Chips	Land Clearing Debris
Ash Content (% dwb)	0.26	2.6	1.4
Percent of Mass in Accept Fraction of this process	91	64	89
Cumulative Percent of Mass in Accept Fraction	85	28	60

The above table shows that the fuel chips continue to be clean, the arborist chips are about the same quality as after simple screening , and the land clearing debris is now less than 1.5 percent ash, sufficient to meet the tightest export pellet fuel specifications.

Table 5. Summary of material characteristics after wet processing though Debarker Module

	Fuel Chips	Arborist Chips	Land Clearing Debris
Ash Content (% dwb)	0.23	2.35	1.05
Percent of Mass in Accept Fraction of this process	94	80	92
Cumulative Percent of Mass in Accept Fraction	87	34	61

Of particular interest in the above table is that the cumulative percent of mass in the accept fraction after two-deck screening and wet debarking retained 87 percent of the clean chips and 61 percent of the land clearing debris, both of which were in the expected range for those materials. Screening and wet debarking of the arborist chips removed more than 65 percent of the mass, which would make the process uneconomical for this type of very low grade biomass – also an expected result.

Summary and Conclusions

Our beneficiation objectives listed *ash content* as the single most important measure of woody biomass feedstock quality. Ash is a generally accepted indicator that essentially integrates the level of bark, dirt, and other contaminants within a sample of biomass. Thus, a key measure of success is how well we reduce the ash content of low grade woody biomass. The ash content for each treatment is reported in the tables above, but we will summarize the ash results below so the reader can follow the cumulative effects of our cleaning steps.

Table 6. Summary of ash content at the end of each treatment step.

	Ash Content (% mass dwb)		
	Fuel Chips	Arborist Chips	Land Clearing Debris
Raw Material as Received	0.3	3.2	12.3
After Initial Two-Deck Screen	0.3	2.6	2.1
After Dry / Wet Debarking	0.3 /0.23	2.6 / 2.4	1.4 / 1.1

The above table shows that the fuel chips were as clean as they could be prior to processing and remained at about 0.3% ash throughout the process. This is clean enough to be used for residential fuel pellets, particle board surface and MDF composite panel surface material. The arborist chips had surprisingly low 3.2 % ash upon delivery in spite of very high bark and needle content. Cleaning with the double deck screen was sufficient to remove much of the needles and reduce the ash to about 2.6% which is sufficient for export grade pellets and torrefied coal replacement fuels. We were pleasantly surprised by the performance of our beneficiation process on ground land clearing debris. The initial ash content of 12.3% was typical of other samples we have worked with over the past five years. As we expected, screening alone dramatically reduce the ash content. We expected the ash content after initial two-deck screening to be in the 4-6 percent range, but achieved 2.1 percent after screening. Subsequent processing through the dry debarker essentially cut the ash content in half again to 1.4 percent which was sufficient to meet export pellet quality.

Acknowledgment

Development was supported in-part by the NIFA Small Business Innovation Research program of the U.S. Department of Agriculture, grant numbers 2008-33610-18880 and 2009-33610-101114. Any opinions, findings, and conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

References

Alex Marvin, W., L. D. Schmidt, et al. (2012). "Economic Optimization of a Lignocellulosic Biomass-to-Ethanol Supply Chain." Chemical Engineering Science **67**(1): 68-79.

ASABE (2008). Moisture Measurement - Forages. ASAE Standard S358.2 DEC1988 (R2008). ASABE Standards. St. Joseph, MI, American Society of Agricultural and Biological Engineers**:** 2.

Bailey, C., J. F. Dyer, et al. (2011). "Assessing the rural development potential of lignocellulosic biofuels in Alabama." Biomass and Bioenergy **35**: 1408-1417.

Barfield, B. J., J. F. Clarke, et al. (1992). Economics and sustainability of global biomass energy systems. St. Joseph, MI, American Society of Agricultural and Biological Engineers.