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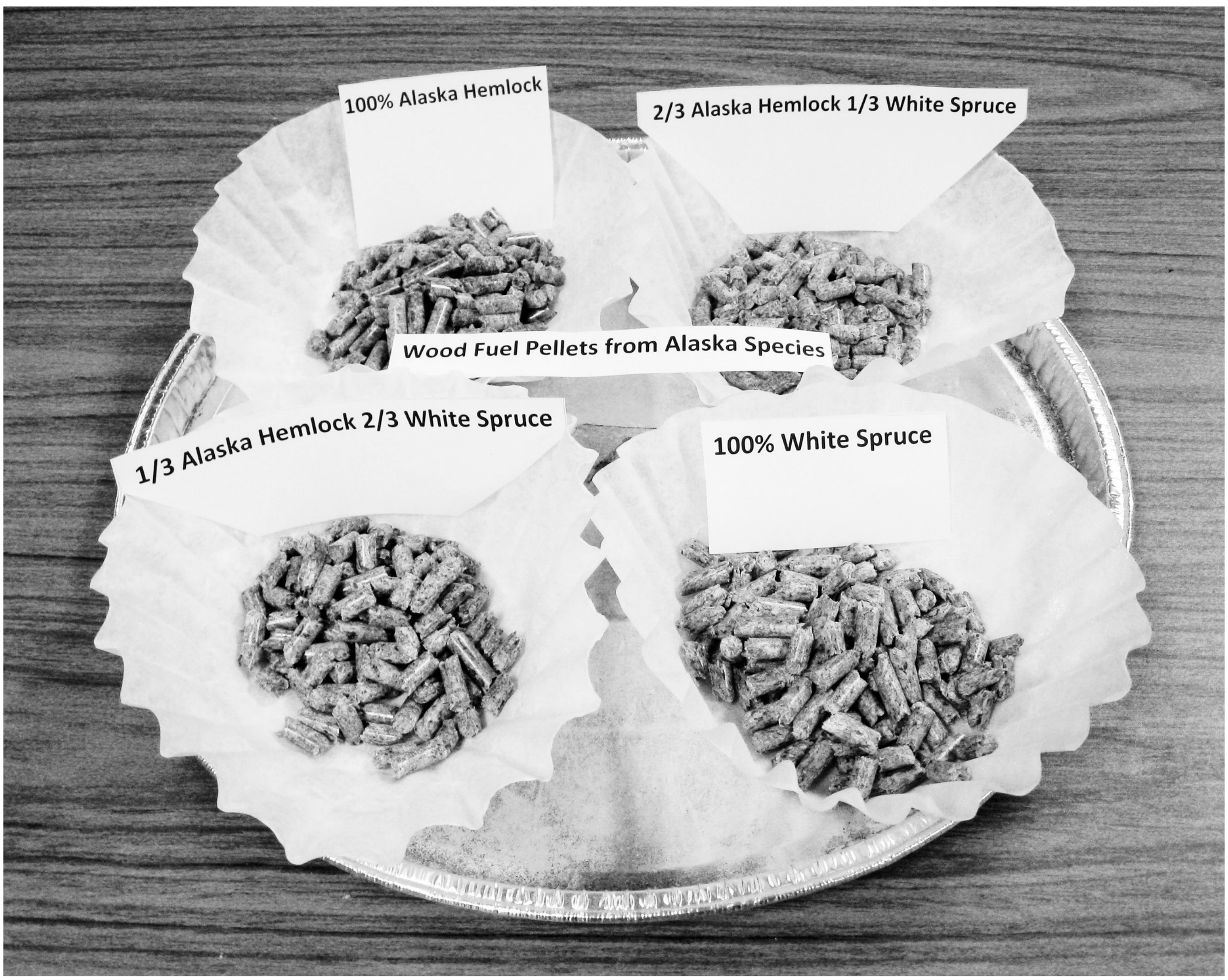
Production of Wood Pellets From Alaska-Grown White Spruce and Hemlock

Allen M. Brackley and Daniel J. Parrent



Authors

Allen M. Brackley is a research forester, U.S. Department of Agriculture, Forest Service, Alaska Wood Utilization Research and Development Center, 204 Siginaka Way, Sitka, AK 99835; and **Daniel J. Parrent** is a wood utilization specialist, Juneau Economic Development Council, 204 Siginaka Way, Sitka, AK 99835.

Cover photograph by Allen M. Brackley.

Abstract

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An extensive literature review failed to locate any information relative to the pelleting characteristics of hemlock species—western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.)—that grow in Alaska. To determine more about the pelletizing properties of the species, arrangements were made with a pelleting company to conduct test runs using mixtures of pure Alaska-grown hemlock and combinations with white spruce (*Picea glauca* (Moench) Voss). The test runs were conducted by using the same methods and procedures that the firm had been using in the production of white spruce pellets. The initial tests with Alaska hemlock resulted in pellets that were visually similar to those that the firm had been producing from spruce. Laboratory testing indicated that pellets made entirely of Alaska hemlock, or of Alaska hemlock and spruce mixtures, met most 2008 Pellet Fuels Institute (PFI) premium pellet and/or standard pellet specifications, with a few exceptions. Given recent (October 17, 2010) changes to the PFI pellet specifications, pellets made entirely of hemlock, or of hemlock and spruce mixtures, could meet all premium pellet specifications with minor adjustments to the manufacturing process.

Keywords: Wood pellets, pellet production, pellet formation, Alaska hemlock, white spruce.

Introduction

The charter of the Alaska Wood Utilization Research and Development Center (AWURC) in Sitka, Alaska, states that the unit is responsible for conducting research projects that have the potential to help rebuild and maintain the forest products industry in Alaska. A second charge is to conduct research that improves conditions in the rural communities that are embedded in Alaska national forests.

During the past 10 years, there has been increasing interest in the use of biomass from the Nation's forest lands as a source of renewable energy (Niebling et al. 2010, Patton-Mallory 2008, Perlack et al. 2005, PR.com 2009, Spelter and Toth 2009). Given the national focus on renewable energy, AWURC has conducted a number of projects to evaluate biomass issues at the national, international (Nicholls et al. 2008, 2009), and regional levels (Brackley et al. 2010, Nicholls et al. 2010).

Most of the land in southeast Alaska is part of the Tongass National Forest (Nowacki et al. 2001, USDA FS 2008). Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), collectively referred to as Alaska hemlock, are the major species growing on the forest lands of southeast Alaska, making up approximately 56 percent of total growing-stock volume (van Hees 2003). It is not possible to differentiate between the two hemlock species in the log form. The Sitka spruce (*Picea sitchensis* (Bong.) Carr.) component is approximately 28 percent of total growing-stock volume (van Hees 2003). The properties of this species are similar to white spruce (*Picea glauca* (Moench) Voss).

There are limited volumes of sawmill residues in the region (Brackley et al. 2006). Given the limited sawmill residuals, the major source of biomass for renewable energy is in unutilized portions of harvested trees, and in rough and rotten trees that are unsuitable for use as saw logs. It is also possible that partial cutting of young-growth stands may result in additional volumes of material suitable for use in energy applications (TFRT 2008).

Use of local species for production of energy products in Alaska has been the topic of several state and regional conferences and many less formal discussions. Given the expressed interest in renewable energy products, an effort was made to locate any project reports that included specific references to species that are indigenous to southeast Alaska. The literature review failed to locate a specific reference relative to the pelleting characteristics of these species, but located firms in other regions of North America (CRE 2010) that advertised pellet products based on a similar species, eastern hemlock (*Tsuga canadensis* (L.) Carr.). The review also identified a firm in Canada (General Biofuels Canada [GBC]) that announced plans to build a large pellet production facility in the vicinity of Terrace, British

Columbia, that may use western hemlock (EIN 2010), at least in part. In the news release, GBC reported that the plant would produce 500,000 metric tons per year of industrial wood pellets. The material would be exported to utilities and industrial firms in Asia and Europe. Raw material for the plant will be supplied by local British Columbia forest license holders. The source (EIN 2010) states, "The British Columbia Ministry of Forests has expressed a willingness to meet any supply shortfalls with additional license capacity if required."

Literature Review

The original objective of this effort was to locate articles that specifically referenced use of eastern or western hemlock in the production of wood fuel pellets. A considerable search, however, failed to locate any articles that specifically referenced or documented tests of hemlock pelletization. The authors found that numerous factors affected the process of pellet production (Lever n.d., Tumuluru et al. 2010, Wilson 2010,.), including characteristics of the equipment processing variables, production parameters, and the physical and chemical bonding mechanisms that, in combination, are part of the process of producing pellets. Leaver (n.d.) stated: "Each wood used as feedstock has specific polymeric characteristics and thus specific temperature, pressure, and moisture characteristics at which it will begin to soften and form a pellet. Thus, the pelleting process is quite material specific and the more consistent the feedstock, the more stable the pelleting process." The success or failure of any particular test for producing pellets may result from a combination of equipment-related variables and their impact on the physical characteristics of the furnish, some of which may be species-specific characteristics. Given these findings, the authors have included a short review of existing standards and production procedures to provide information that all pellet manufacturers must consider.

Standards for Pellet Production

Since 1988, the U.S. Environmental Protection Agency (EPA) has been updating performance standards for wood heaters used in residential construction (Hager 2010, PFI 2010). As part of this program, EPA is also requiring standardization of pelletized fuel. The EPA activity will result in changes to the Pellet Fuel Institute (PFI) voluntary standard that has existed since 2008. These changes were announced as this report was nearing final completion and have been incorporated into the text.

The 2008 PFI standard that existed at the start of this project was a voluntary, uniform standard for use by member mills when labeling wood pellets for sale (PFI 2008b). The standard defined pellet quality in terms of bulk density, acceptable diameter and length, allowable percentages of fines "at the mill gate," levels of inorganic ash, moisture content wet basis [wb],[1] chloride content, and durability index. The durability index (PFI 2010c) is "…a standardized parameter for specifying the ability of the fuel pellets to resist degradation caused by shipping and handling." Table 1 summarizes the 2008 PFI standards for various grades of fuel.

Engineers interested in energy values use moisture content as a percentage of wet or green weight.

Table 1—Pellet Fuels Institute (PFI) 2008 residential/commercial densified fuel standards

Fuel property	PFI super premium	PFI premium	PFI standard	PFI utility
		Pounds per cubic foot		
Bulk density	40.0–46.0	40.0–46.0	38.0–46.0	38.0–46.0
		Inches		
Diameter	0.250–0.285	0.250–0.285	0.250–0.285	0.250–0.285
		Millimeters		
Diameter	6.35–7.25	6.35–7.25	6.35-7.25	6.35–7.25
Pellet durability index	≥97.5	≥97.5	≥95.0	≥95.0
		Percent		
Fines (at mill gate)	≤0.50	≤0.50	≤0.50	≤0.50
Inorganic ash	≥ 0.50	≥ 1.0	≥ 2.0	≥ 6.0
Length (> 1.5 inches)	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Moisture (green basis)	≤ 6.0	≤ 8.0	≤ 8.0	≤ 10.0
		Parts per million		
Chloride	≤ 300	≤ 300	≤ 300	≤ 300
Ash fusion	NA	NA	NA	NA
Heating value[a]	As received ± 2SD	As received ± 2SD	As received ± 2SD	As received ± 2SD

NA = Not available.
[a] There is no required value or range for heating value. It is required that the mean higher heating value in British thermal units per pounds and ash content be printed on the label using a bar scale to represent the mean value ± 2SD.
Source: PFI 2008b.

[1] There are two methods for reporting the moisture content of forest products. Wood Technologists—scientists working with most solid forest products such as lumber, plywood, and particleboard—report moisture content in relation to the bone dry weight of the material, and the resulting values are referred to as dry basis (db). Engineers concerned with energy relationships or the pulp and paper industry, however, report moisture content in relation to the original wet weight of the material; the resulting values are referred to as wet basis (wb). Moisture content values expressed as percentage values can be converted from one basis to the other using the formula $db = [(wb/100)/(1 - wb/100)] \times 100$ or $wb = [(db/100)/(1 + db/100)] \times 100$. A moisture value of 50 percent wb converts to 100 percent db, and dry basis values can be in excess of 100 percent. In this report, the authors have followed moisture content values with (db) or (wb) to identify the basis (denominator of the moisture content formula) used to obtain the value.

The American Lumber Standards Committee may certify and enforce pellet fuel standards.

On October 7, 2010, the PFI Board of Directors unanimously passed an updated version of the PFI North American Residential/Commercial Densified Fuel Standards (PFI 2010a). Important features of the new program include initial accreditation, certification of mills, monthly third-party inspection, sampling, testing, and overall program oversight. Table 2 compares the 2008 and 2010 board-approved changes that have been forwarded to EPA. Changes in specifications are shown in bold print. The PFI is also negotiating with the American Lumber Standards Committee (ALSC) to provide certification and enforcement regulations (ALSC 2010). Under the new enforcement regulations, a mill that wants to use PFI marks must apply to the ALSC Board of Review for accreditation. Prior to awarding accreditation, the ALSC Board of Review will require that the applicant mill have a suitable quality control program that includes a third-party production auditing program. The auditing agency will initially certify product quality, and thereafter quality control sampling will be at a minimum rate of one sample per every 1,000 tons of production (ALSC 2010). Under section 5, (ALSC 2010) the board of review field staff will be responsible for monitoring agency performance. The four types of monitoring will include (ALSC 2010):

Table 2—Comparison of Pellet Fuel Instifiute (PFI) 2008 standards and 2010 PFI Board of Directors approved standards

	Super premium grade		Premium grade		Standard grade		Utility grade	
Fuel property	6/18/2008	10/7/2010	6/18/2008	10/7/2010	6/18/2008	10/7/2010	6/18/2008	10/7/2010
Bulk density	40.0–46.0	This grade eliminated from 2010 standard	40.0–46.0	40.0–46.0	38.0–46.0	38.0–46.0	38.0–46.0	38.0–46.0
Diameter (inches)	0.250–0.285		0.250–0.285	**0.230–0.285**	0.250–0.285	**0.230–0.285**	0.250–0.285	**0.230–0.285**
Diameter (mm)	6.35–7.25		6.35–7.25	**5.84–7.25**	6.35–7.25	**5.84–7.25**	6.35–7.25	**5.84–7.25**
Pellet durability index	≥97.5		≥97.5	**≥96.5**	≥95.0	≥95.0	≥95.0	≥95.0
Fines (percent at mill gate)	≤0.50		≤0.50	≤1.0	≤0.50	**≤1.00**	≤0.50	**≤1.00**
Inorganic ash percent	≤0.50		≤1.0	≤1.0	≤2.0	≤2.00	≤6.0	≤6.0
Length (percent > 1.5 inches)	≤1.0		≤1.0	≤1.0	≤1.0	≤1.0	≤1.0	≤1.0
Moisture percentage (wet basis)	≤6.0		≤6.0	≤6.0	≤8.0	**≤10.0**	≤10.0	≤10.0
Chloride (ppm)	≤300		≤300	≤300	≤300	≤300	≤300	≤300
Not mandatory: Ash fusion Heating value								

Changes in specifications are shown in bold print.
Source: PFI 2008b, PFI 2910c.

1. Random sample survey inspections (at manufacturer sites—section 5.1.1).
2. General inspections (see section 5.1.2).
3. Destination inspections (conducted in market areas where pellets are sold—section 5.1.3).
4. Recall inspections, defined as inspections resulting from finding serious deficiencies during a random sample, general, or destination inspection. The objective of recall inspections is to determine that corrective action has been taken.

As previously noted, the above changes were in process as the final draft of this report was being prepared.

When this report was initially prepared, standard specifications for wood pellets in Canada (Peksa-Blanchard et al. 2007) did not exist. However, in early 2010, the PFI Web site (http://www.pelletheat.org/2/index/index.html) listed four Canadian firms as registered "manufacturer" members. A similar check of the Web site on October 25, 2010, indicated that five Canadian manufacturer members (one of which also operated a plant in Pennsylvania), one Canadian university, and several European organizations are listed as PFI associate members.

As previously noted, major additions and changes were made to the PFI Web site on October 25, 2010. The title of one of the new documents was "North American Certification of Residential/Commercial Densified Fuel." Note the use of "North American" in reference to certification. The Web site also announced that PFI was actively negotiating a contract with ALSC to assume responsibilities as the "certification body" for purposes of implementation of the PFI standards. The result of all of the PFI activities is that Canadian pellet producers have the option of adopting the PFI standards, and selected or designated Canadian agencies will become certifiers and accrediting agencies of the PFI standard in a manner similar to Canadian lumber producers under the American Lumber Standard (NIST 2010).

The roots of the European Energy Charter (EEC) date back to the mid 1980s (ECS 2010). Under the terms of the EEC (ECS 2004), each signatory nation has agreed to pass energy legislation to reduce carbon emissions. Several of the countries have passed legislation to substitute renewable biomass energy sources for fossil fuels. In the early years of the EEC, these nations created their own standards for wood pellets. At this time, standards for production of pellets in Europe are in a state of flux. Alakangas (2010) stated:

> The European Committee for Standardization, CEN/TC TC335, has published 27 technical specifications (pre-standards) for solid biofuels during the period 2003–2006. Now these technical specifications are being

upgraded to full European standards (EN). Where EN-standards are in force the national standard of member countries has to be withdrawn or adapted to these EN-standards.

Standards for pellets produced and sold in the European Union are in a state of flux.

Prior to 2010, Hahn (2004) reported that the major pellet-using nations of Europe (Austria, Sweden, Germany, Italy, and Great Britain) had established standards for pellet products. These standards will now be replaced by three new standards. The first, EN 14961-1, covers pellets for general use that includes specific reference to pellets from different biomass raw materials. Second, EN 14961-2 covers wood pellets for nonindustrial use. Finally, EN 14961-6 provides standards for nonwoody pellets for nonindustrial use.

The pellet standards developed by the European Union (EU) are presented in table 3. Note that pellets for domestic use will be 6 or 8 mm (0.234 or 0.315 in) in diameter. The pellets greater than 8 mm (0.315 in) are used in industrial and commercial applications. Both the EN (Alakangas 2010) and PFI (2008b, 2010c) require that pellets meet specific conditions with respect to length, diameter, bulk density, percentage of fines, ash percentage, moisture content, and heating value. Neither the PFI or EN specify a standard for heating value, but both require reporting of the average heating value of the pellets on the package label. Both standards require reporting of chloride (parts per million [ppm] in the United States) or chlorine (percentage of weight/dry basis EU). The EU standards also require reporting percentages of nitrogen and sulphur. The most recent updates to the PFI standards (PFI 2010b) increase the amount of fines allowed in the standard grade of pellets from ≤ 0.5 percent to ≤ 1.0 percent, but this level must be maintained at the "market level" as opposed to the previous standards (PFI 2008b) "at the mill gate."

Both PFI (2010b) and EN (Alakangas 2010) require reporting of a durability index that is indicative of degradation from handling and shipping. Several approaches and methods for durability testing are outlined in a report by Temmerman et al. (2006). In the PFI (2008b, 2010b) standards, a slightly modified version of the Kansas State University method as outlined in American Society of Agricultural and Biological Engineers (ASABE) S269.4 (ASABE 2007) is used to evaluate durability. In the testing process, a 500 g (1.1 lb) sample of wood pellets is tumbled for 10 minutes in a baffled box and sieved on a 1/8-in (3.175-mm) screen (PFI 2010b). The requirements outlined for feed pellets in standard 5.2.2 (ASAE 2007) states that "Fines shall be determined by screening a sample on wire sieve having openings just smaller than the nominal pellet diameter." Alakangas (2009) described the same baffled box testing device, built to the same dimensions as specified for durability testing in the EU standard. Duration of the test and

Table 3—Specification of properties for pellets (EN 14961-1)

Origin of pellets:

N or I[a]	Code	Source
N	1	Wood biomass
N	2	Herbaceous biomass
N	3	Fruit biomass
N	4	Blends

Dimension:

N or I	Code	Diameter (mm)	Code	Length (mm)
N	D 06	6 ± 1.0	3	15 ≤ L ≤ 40
N	D 08	8 ± 1.0	3	15 ≤ L ≤ 40
N	D 10	10 ± 1.0	3	15 ≤ L ≤ 40
N	D 12	12 ± 1.0	3	15 ≤ L ≤ 40
N	D 25	25 ± 1.0	10	10 ≤ L ≤ 50

Moisture (as received):

N or I	Code	Moisture content
		Percent
N	M10	≤ 10
N	M15	≤ 15

Percentage ash (dry weight basis):

N or I	Code	Percentage of dry weight
N	A0.5	≤ 0.5
N	A0.7	≤ 0.7
N	A1.0	≤ 1.0
N	A1.5	≤ 1.5
N	A2.0	≤ 2.0
N	A3.0	≤ 3.0
N	A5.0	≤ 5.0
N	A7.0	≤ 7.0
N	A10.0	≤ 10.0
N	A10.0+	> 10.0

Mechanical durability (DU fine weight as percentage of original sample weight):

N or I	Code	Percentage of original weight
N	DU97.5	≥ 97.5
N	DU96.5	≥ 96.5
N	DU95.0	≥ 95.0
N	DU95.0	< 95

Amount of fines after production and packaging (fine weight as percentage of original sample weight):

N or I	Code	Percentage of original weight
N	F1.0	≤ 1.0
N	F2.0	≤ 2.0
N	F3.0	≤ 3.0
N	F5.0	≤ 5.0
N	F5.0+	> 5.0

Additives:

N — Type and content of pressing aids, slagging inhibitors, or any other additive must be stated on label

Bulk density (BD as received kg/M^3):

N or I	Code	kg/M^3	(lbs/ft^3)
N	BD550	≥ 550	≥ 34.3
N	BD600	≥ 600	≥ 37.4
N	BD650	≥ 650	≥ 40.6
N	BD700	≥ 700	≥ 43.7
N	BD700+	> 700 (minimum value stated)	> Stated value
N	Q or net calorific value as received = MJ/kg or EN = kWh/kg		

Sulphur S (w-percent dry basis):

N or I	Code	Weight	
		Percent	
N or I	S0.02	≤ 0.02	N for chemically treated,
N or I	S0.05	≤ 0.05	I for not chemically treated
N or I	S0.08	≤ 0.08	
N or I	S0.10	≤ 0.10	
N or I	S0.20	≤ 0.20	
N or I	S0.20+	> 0.20 (maximum value stated)	

Nitrogen N (w-percent dry basis):

N or I	Code	Weight	
		Percent	
N or I	N0.3	≤ 0.3	N for chemically treated,
N or I	N0.5	≤ 0.5	I for not chemically treated
N or I	N1.0	≤ 1.0	
N or I	N2.0	≤ 2.0	
N or I	N3.0	≤ 3.0	
N or I	N3.0+	> 3.0 (maximum value stated)	

Chlorine Cl (w-percent dry basis):

N or I	Code	Weight	
		Percent	
N or I	Cl0.02	≤ 0.02	N for chemically treated,
N or I	Cl0.03	≤ 0.03	I for not chemically treated
N or I	Cl0.07	≤ 0.07	
N or I	Cl0.10	≤ 0.10	
N or I	Cl0.10+	> 0 (maximum value stated)	

[a] Normative (N) items are required on the product label. Informative (I) items may be included at the option of the manufacturer.

Source: Alakangas 2010.

rotational speed specified in the EU standard (Alakangas 2009) are in agreement with those specified in ASABE (2007). The sieve size used in the EU procedures is slightly different, but the ultimate testing results should be comparable.

In summary the PFI and EU standards are essentially the same. The EU standard recognizes pellet diameters of 6, 8, 10, 12, and 25 mm. Most of the pellets for domestic or home use will be 6 or 8 mm. The PFI (PFI 2010b) standard is focused on pellets that conform to the 6 mm EU product. Table 4 presents the information required on a label by the EU standards. The label information in the table is from test runs to produce pellets from hemlock grown in Alaska, as reported by Twin Ports Testing in Lake Superior, Wisconsin.

Table 4—Example of label required by EN 14961-2

Producer	Alaska Pellet Company
Origin	1.0 wood biomass
Trade Form	Pellets—Class A1 (a0.5)
Country of origin	Alaska, United States
Normative (EN 14961-2)	
Dimension	D06 (diameter = 6 ± 0.5 mm) and length ≤ 5× diameter
Moisture	M10 (≤ 10 percent)
Ash	A0.5 (≤0.5 percent)
Mechanical durability	DU96.5 (≥ 96.5 percent)
Amount of fines	F1.0 (≤ 1.0 percent)
Net calorific value, Q	Q ≥ 5.1 kWh/kg
Additives	None
Bulk density	BD700+ (< 755 kg/m^3 or 47.21 lbs/ft^3)
Chemical composition	N 0.3 (≤ 0.3% nitrogen), S 0.02 (≤ 0.02% sulfur), Cl 0.02 (≤ 0.02% chlorine)
Ash melting behavior	Not available
Minor elements	Informative only, not required

Data in the above table taken from tests of hemlock pellets produced by Alaska Pellet Company. The data has been converted to the form required by EN 14961-2 as of the date of the testing of the Alaska product. EN standards are in a state of flux and may change after date of publication.

The Bonding Process

Several recent reports and theses (Jonsson 2009, Kaliyan and Morey 2006, Sokhansan et al. 2005, Wilson 2010), when reporting the various bonding mechanisms that are essential to the pelleting process, make reference to a 1962 article by H. Rumpf, "The strength of granules and agglomerates," which appeared in a book titled *Agglomeration*, edited by W.A. Knepper and published by Wiley Interscience, and which reported the proceedings of the 1961 Agglomeration Symposium. Reference is made to *Agglomeration* at the following Web site: http://www.agglomeration.org/Information/tabid/65/AgglomerationBooks.aspx. We were unable to locate a copy of the original Rumpf article, but did locate an article by Sastry and Fuerstenau (1973) that appears to be very close to the original source (it cites Rumpf as a source) and in agreement with the more recent works. Quoting from Sastry and Fuerstenau (1973):

> Forces contributing to the formation of green pellets from particulate solids are of two kinds: natural (or physical) and applied (or mechanical). The natural forces responsible for the formation of agglomerates can result from a number of sources: (a) the attraction between solid particles due to van der Waals forces, magnetic forces, or electrostatic charges, (b) the interlocking effects between particles, depending on the shape of particles, (c) the adhesional and cohesional forces in bridging bonds, which are not freely moveable, and, very importantly, (d) the interfacial and capillary forces due to the presence of a liquid phase. The strength of green agglomerates results from the physical forces that hold the particles together; and the magnitudes of these physical forces are dependent on the particle size, surface charge, crystal structure, the proximity of the particles, the amount of additives, and other physical-chemical properties of the system.

Pellets can be produced from any biomass material.

Pellets can be produced from almost any biomass material. The preparation process focuses on reduction of material to form particles with optimum geometric configuration. The surface properties of the particles are extremely important, as are the forms and levels of moisture in the material. Chemical composition in terms of cellulose, hemicelluloses, and lignin are also important characteristics. Just prior to feeding the mixture or furnish into a pelleting machine it can be described in terms of bulk density, temperature, moisture content, and chemical components. Chemical components may be determined using procedures such as Klason lignin or acid detergent lignin procedures (Hatfield et al. 1994) or spectrographic analysis.

The pelleting process itself subjects the prepared raw material to heat and pressure as the material is forced through a die. The interaction between the mix of materials and the production equipment produces compaction and mechanical interaction of the particles. Friction caused by forcing the material together and pressing against the die generates heat that is applied to the raw material. As heat and pressure are applied, the remaining water temporarily fills cavities that are decreasing in size. The additional pressure causes attraction of the particles by capillary action. Ultimately, much of this moisture exits the final product and there is uncertainty about the role of this phase on ultimate pellet quality. Van der Waals forces contribute to the process of pellet formation. If the critical temperature and pressure for melting (plasticizing) of native unaltered lignin is obtained, upon cooling, the lignin will function as an adhesive and maintain the structural integrity of pellets.

Much of the research by the pulp and paper industry deals with lignin as an extracted product, and the extraction processes results in a modified form of the material. Kelley et al. (1987) cited research by Irvine (198) using differential scanning calorimetry (DAS) of whole wood that revealed a single glass transition point[2] (Tg) between 50 and 120 °C (122 to 248 °F) which was assigned to lignin. Kelley et al. (1987) also reported that the Tg was affected differently by water. The research by Kelley et al. (1987) determined that wood material plasticized with ethyl formamide followed Williams-Landel-Ferry behavior in the temperature range Tg to Tg + 85 °C. It must be stated that Tg is lower than the melting point and that melting takes place at some temperature above Tg + 85 °C (Tg + 185 °F). By definition, the transition state between Tg and Tg + 85 °C is constant, but the above research deals with altered lignin as opposed to the material in the native unaltered form. Regardless, attaining the transitional state (Tg) creates an increase in the potential for binding and bonding in a process such as pelleting. At the melting point of lignin, fusion becomes a reality. The temperatures generated in the pelleting process are not sufficient to obtain fusion.

Recent research relative to welding of wood provides additional knowledge about the properties of lignin in the unaltered form. Numerous papers have been published about the process and resulting technology (Gerber and Gfeller 2000, Gfeller et al. 2004, Pizzi et al. 2003, Pizzi et al. 2004). The most relevant point reported by Pizzi et al. (2003) is the statement: "…the temperature of just the bondline reaches 170 °C (338 °F) or higher during the welding." This temperature is much higher than the Tg of lignin and hemicelluloses, above which these materials are known to flow (Kelley et al. 1987). Melting of some of the major structural, polymeric wood constituents occurs and can be observed by scanning electron microscopy. If pressure is applied at these temperatures, lignin will glue cellulose together, which is solidified upon cooling. We note that the pelleting process as it exists generates temperatures slightly lower than the Tg and are not high enough to weld the particles together.

In combination, the above factors contribute to the process of pellet formation. A more detailed explanation requires a knowledge and understanding of physical chemistry.

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[2] Glass transmission point or temperature is that temperature at which a polymer changes from a hard glassy form to an elastic one (Szczesniak et al. 2008).

Pelletizing Material

Wood (1987) reported that "…pelleting of animal feeds has become a firmly established process within the feed industry." Research conducted by Wood (1987) tested pellet quality (durability) resulting from inclusions of denatured soy protein and native tapioca starch in mixtures of animal feeds. In this research, it was determined that improvements in durability were greatest for raw protein. Pellet hardness was improved with increasing levels of pregelatinized starch content.

Lehtikangas (2000, 2001), employed by the Department of Forest Management and Products at the Swedish University of Agriculture Sciences, conducted research to evaluate the storage effects on wood pellets made from sawdust, logging residues, and bark. Pellets made from fresh logging residues were found to absorb the greatest amount of water and have the lowest durability. In general, all pellets stored for 5 months showed minor but notable reductions in quality. In the second study, a mixture of materials from Norway spruce (*Picea abies* (L.) Larst.) and Scots pines (*Pinus sylvestris* L.) were evaluated. In this project, nine pellet formulations from varied sources (fresh and stored sawdust, bark, and logging residues) were obtained from producers. The resulting pellets were evaluated based on moisture content, heating value, content of ash, sulphur, chlorine, and Klason lignin. Other factors reviewed included pellet dimensions, bulk density, individual pellet density, durability, and ash sintering as it relates to slag formation.[3] In this study, durability of wood-based pellets was determined to be significantly increased by greater lignin content and moisture content of wood particles delivered to the pelleting machine. Bark pellets demonstrated good durability regardless of moisture content. It should be noted that the maximum moisture content evaluated (20 percent, wb) was for an all-bark mixture. Based on an interpolation of the figures in the report, pellet moisture content from other stock types ranged between 6 and 15 percent (wb).

Given the increasing interest in renewable energy and pellets during the past 10 years, several reports (Kaliyan and Morey 2006, Peksa-Blanchard et al. 2007, Wilson 2010) have included extensive literature reviews to summarize information relative to material characteristics, processing methods, and production parameters for pellet production. These papers include research relative to pelletization of both agricultural feedstocks and forest-based material. Wilson (2010) and Kaliyan and Morey (2006) identified the factors that affect pellet strength and durability as moisture content, particle size, preheating and steam conditioning, and inclusion

[3] Sintering refers to the agglomeration of powders into solids. In this instance we are concerned with the agglomeration of ash into slag and the strength of the resulting slag formed during the burning process. Slag can affect the performance of pellet burners. A complete discussion of this problem in contained in Öhman et al. (2004).

of binders. Leaver (n.d.), in a report concerned with the pelleting of feedstock, stated that ambient conditions, both temperature and relative humidity, can affect pelletability. He noted that "northern installations routinely have a problem reaching as high a mash temperature in winter as in summer." Kaliyan and Morey (2006) also reported the effect of mixing various raw materials and cited a report by Bradfield and Levi (1984). In the Bradfield and Levi (1984) project, furnish for pelleting came from wood and bark of six common southern hardwoods—red maple (*Acer rubrum* L.), southern red oak (*Quercus falcata* Michx.), sweetgum (*Liquidambar* L.), tupelo (*Nyssa* L.), white oak (*Quercus alba* L.), and yellow poplar (*Liriodendron tulipifera* L.)—as well as loblolly pine (*Pinus taeda* L.). Pellets were produced by using a laboratory system. In these tests, hardwood mixtures without bark did not pelletize. Furnish formulations that were a mixture of wood and bark mixed to the natural proportions produced pellets that were relatively durable. The pure pine wood pelleted easily and produced hard, durable pellets.

Both Wilson (2010) and Kaliyan and Morey (2006) reviewed the binding mechanisms or physical forces that take place in the process of pellet formation. This included solid bridges that are developed by diffusion of molecules from one particle to another at point of contact; attraction forces between solid particles (chemical bonds, hydrogen bridges, and van der Waals forces); mechanical interlocking of particles resulting during the compression process; adhesion and cohesion forces (noted only by Kaliyan and Morey [2006]), which occur when the mixtures include highly viscous binders such as molasses and tar that adhere to the surface of solid particles to generate strong bonds; and interfacial forces and capillary pressures that are created during the three stages of the densification process (pendular, funicular, and capillary states). Both sources noted the importance of moisture as essential to the development of interfacial and capillary pressure. Also, the bonds created by interfacial forces and capillary pressure disappear once the liquid evaporates, but they are critical to the cohesive forces in the final pellet.

As mentioned, the Kaliyan and Morey (2006) paper included a literature review or synthesis of factors that contribute to strength and durability of densified products. Wilson (2010), however, reasoned that the effect of tree species on pellet durability is through variation in lignin content. His study evaluated pellet durability from furnish mixtures that were characterized in terms of Klason lignin content, particle size distribution, triaxial compression testing, and particle shape. Wilson (2010) concluded that lignin content differs with tree species, but it did not appear to have an impact on pellet durability. There were significant differences between the bulk material properties that produced the highest and lowest levels of durability in this project. In summary, Wilson (2010) reported that the lowest durability was in pure pine pellets with a furnish moisture content of 10 percent (wb). The highest durability was for red oak pellets with a furnish moisture content of 10 percent (wb). Wilson recommended that additional research be focused on furnish bulk material characteristics. Specific furnish characteristics recommended for review were the bulk modulus and elastic response, along with a review of the geometric and surface characteristics of the particle components on compaction behavior. Wilson noted that the techniques used in powder mechanics and the pharmaceuticals industry that characterize and predict the behavior of irregular particle distributions should be applied to the pelleting process.

Stahl et al. (2004) conducted a project to evaluate processes of biomass drying and effects on wood pellet quality. Pellets, green material, and dry furnish were supplied by producers. Moisture content (wb) of green material ranged from 41.23 to 53.54 percent, dry furnish from 6.05 to 11.68 percent, and pellets from 6.00 to 7.79 percent. This project also reported that most of the terpenes in the sawdust were lost in the drying process. High levels of terpenes in the finished product increase the energy content. Leaver (n.d.) reported that the optimum moisture content (wb) of feedstock for pelleting agricultural products was 10 percent ± 1 percent.

The available literature is in general agreement relative to the impact of source material (solid wood, bark, and foliage), dimensional characteristics of particle size, and moisture content on the pelleting process. Wilson (2010) reported that for six southern hardwoods and one softwood species there was no relationship between Klason lignin and pellet durability. Lehtikangas (2001), working with Norway spruce and Scots pine, noted that pellets made of bark and logging residues had higher Klason lignin values than pellets produced from sawdust. He also noted that lignin content increased with storage time of material prior to production. Pellets made from material with these characteristics had greater durability. The results of Wilson (2010) and Lehtikangas (2001) are somewhat contradictory, but the project by Lehtikangas included bark and storage time as additional factors not fully considered by Wilson. In the production process, the geometry of the die (die length/diameter [L/D] ratio) and gap between the die and the pressure head both have an impact on pellet durability.

Important settings on pelleting machines include die hole configuration, die speed, and the gap between presuure member and die.

Pellet Production Equipment

Production variables also affect the pelleting process. Wilson (2010) and Kaliyan and Morey (2006) noted that die configuration, die speed (referenced in the tangential direction for vertical machines), and the gap between the roller and die are also of concern. The openings in the die matrix are characterized by the ratio of the diameter of the holes to their length. Both sources noted that pellet durability increases as the length of the die holes increases in relation to diameter (L/D ratio). Wilson (2010) stated that this increase in durability is due to increased friction between the feedstock and the die and a resulting increase in temperature. He also reported that too large an L/D ratio results in blockage in the die. Wilson stated that softwood pellet producers commonly use deeper dies (longer L) than hardwood producers. With respect to the gap between the compression source and the die, both authors made reference to a report by Robohm and Apelt[4] that found the optimum gap in feed stock production between the die and compression member to be 2.0 to 2.5 mm (0.008 to 0.10 in). Both authors reported that at a gap thickness of 4.0 to 4.5 mm (0.016 to 0.018 in) there was a significant degradation of pellet quality. Kayliyan and Morey (2006) stated, "The initial increase in pellet quality was due to a dense layer of material compressed through the die as a result of increased shear and prolonged pre-compression. A further increase in gap size resulted in a decreased stability of the feed mash on the edge of the roller and die because of sideways leaking of the feed mash."

In summary, a review of a considerable volume of literature failed to locate any specific reference to the production of pellets from western or eastern hemlock. The literature, however, provides considerable information relative to the pelleting process and possible explanations why any specific attempt to produce pellets from a specific species or species mix might succeed or fail.

Methods

The literature review located one reference (Chow and Pickles 1971) that concerned properties of western hemlock that would affect the pelleting process. The focus of the Chow and Pickles article, however, was thermal softening and degradation of the wood and bark, and no reference to pelleting was included. The literature review also failed to locate any reference to the spruces that grow in Alaska (Sitka spruce (*Picea sitchensis* (Bong.) Carr.), white spruce (*Picea glauca* (Moench) Voss), Lutz spruce (*Picea X lutzii* (Little)), or black spruce (*Picea mariana* (Mill.) B.S.P.). Given this fact, co-author Dan Parrent reviewed feasibility for conducting a preliminary project to produce test batches of pellets from the species of interest.

[4] We have attempted, without success, to locate and reference the original publication by Robohm and Apelt. Based on a check using Google Scholar on December 22, 2010, it was determined that the authors have been cited 37 times. A check of the various citations determined that in fact several articles have been referenced. It appears that the original 1974 publication was in a German Trade Magazine that has not been converted to electronic form. The authors wish to recognize Robohm and Apelt as the source of the information, but are unable to cite a specific published article.

Alaska Pellet Company,[5] a unit of Logging and Milling Associates in Delta Junction, Alaska, was contacted and agreed to make trial runs of western hemlock and white spruce singularly and in combination.

Alaska Pellet Company has been in business for 2 years. The parent company purchased the small pellet mill as a means of converting dry planer shavings and an ever-increasing pile of slabs and edgings into a more valuable product. The ability to produce a valuable product from otherwise value-less raw material created an additional income stream and further diversified the existing operation. The pellet mill requires two to three workers when operating, and may fill work hours when circumstances (such as severe weather conditions) do not allow production elsewhere in the production chain.

Twin Ports Testing of Superior, Wisconsin, a PFI-recognized testing agency, was selected to evaluate the physical and chemical properties of the final products in accordance with PFI standards. Arrangements were made and the trial production runs were conducted in late January 2010.

In the original study plan, it was agreed that Alaska Pellet Company personnel would use their established procedures and equipment to produce the test runs. The production runs would produce pellets from three formulations:

1. 100 percent Alaska hemlock.
2. 67 percent Alaska hemlock and 33 percent white spruce.
3. 33 percent Alaska hemlock and 67 percent white spruce.

During the study, 100 percent white spruce pellets were also produced for comparative purposes. Trial production runs were made during the week January 18 to 22, 2010. Mixtures of feedstock were made on a volumetric basis.

Raw Material

Before the study, Logging and Milling Associates had purchased hemlock logs harvested in the vicinity of Haines, Alaska, and trucked to Delta Junction. This material had been purchased to fill a special order for heavy timbers. The jacket boards, slabs, and edgings from this run were saved for the hemlock pelleting tests. Most of the bark on the hemlock logs was lost during harvesting and subsequent handling.

The white spruce logs for the tests were procured locally in the Delta Junction area. Slabs, edgings, and shim cuts from the spruce were used to produce pellet material. The spruce logs had not been debarked, and it was estimated that the bark component was 15 percent by volume. Alaska Pellet Company routinely produces

[5] The use of trade or firm names in this publication is for reader information and does not imply endorsement buy the U.S. Department of Agriculture of any company, product or service.

pellets from a mixture of barky slabs, planer shavings, and Pendu shavings with an estimated moisture content of 12 to 15 percent dry basis (db) (10.7 to 13.0 percent wb). It was estimated that shavings were 10 percent by volume of the spruce mixture used as raw material.

Material Preparation

Hemlock feedstock consisted of hemlock slab wood, essentially free of bark, kiln dried approximately 2 weeks prior to testing to approximately 5 percent moisture content (db). In this instance, moisture content was determined by using a lumber moisture meter. After moisture content testing, the material was left uncovered outdoors in subzero (°F) temperatures. Moisture content at the time of testing was 9.24 percent (wb) (10.18 percent db), as later determined using laboratory drying methods.

Spruce feedstock consisted of two mixtures. When combined with hemlock, spruce feedstock consisted of spruce slabwood, edgings, and shim cuts, including bark (estimated to make up about 15 percent of the spruce feedstock volume). Slabs were removed from the dry kiln the first morning of the test, and moisture content ranged from 4.8 to 5.1 percent (db), as determined by a lumber moisture meter. In the test of pure spruce, the slabwood was combined with shavings from a Pendu resaw amounting to approximately 10 percent by volume. The moisture content of the Pendu shavings ranged from 12 to 15 percent (db).

Slabs were ground in a Rotochopper Model MC266 horizontal grinder, and further reduced in a hammermill with a 0.190-inch screen. Temperature of the feedstock just prior to pelletizing was not recorded; however, ambient air temperature was approximately -15 to -20 ºF (-26 to -28 ºC).

Pelleting Equipment

Raw material furnish was converted to pellets by using a California Pellet Mill (CPM) Century 100 pellet machine, equipped with a 100 hp electric motor. The ring die is 16 inches in diameter and 2.75 inches thick. Hole diameter is 0.25 inches with an effective zone of 1.75 inches and a 1.00 inch taper zone. The gap between the die and the rollers was set at 1 mm (0.0039 inch). The tangential rotational speed of the compression member was calculated at 13.96 feet per second. As noted above, the outdoor air temperature during the tests was approximately -15 to -20 °F. The mill facilities were unheated, although heat produced by the equipment kept temperatures in the mill reasonably comfortable. During the off hours, heat lamps were used to keep the temperature of the die above freezing.

Pellets produced in the pellet machine are deposited onto an inclined belt conveyor, air cooled with fans, dumped into a trough, augered to a bucket conveyor, and conveyed into a small storage hopper. Cooled pellets are dispensed directly from the hopper, metered, and bagged in plastic as 40-lb units with the Alaska Pellet Company label. The pellets were not screened to remove fines prior to bagging. At this time, the local market currently consumes all pellet products produced by Alaska Pellet Company. To date, none of the local consumers have required PFI certification

Pellets were not screened to remove fines prior to bagging.

A sample of pellets produced from each species mix was loaded into a 0.5-ft^3 U.S. Postal Service "priority mail" flat rate box, lined with a plastic bag. After being filled, the plastic bag was closed to allow minimum interaction with outside moisture. The samples were shipped from North Pole, Alaska, to Twin Ports Testing, Inc., in Superior, Wisconsin, for evaluation. Twin Ports Testing, Inc., is listed on the PFI Web site as a certified testing facility.

Table 5—Chemical properties and energy values for Alaska hemlock and spruce pellets as reported by Twin Ports Testing, Inc., Superior, Wisconsin

Property	Batch 1 (100% WS)	Batch 2 (67% WS; 33% AH)	Batch 3 (33% WS; 67% AH)	Batch 4 (100% AH)
		Percent		
Moisture content of sample	7.84	5.39	6.83	5.79
Ash:				
Moisture free	0.76	0.82	0.55	0.35
As received MC	0.70	0.78	0.51	0.33
Sulfur:				
Moisture free	0.008	0.010	0.009	0.011
As received MC	0.008	0.009	0.008	0.010
		Gigajoules per tonne		
Net calories at constant pressure:				
Moisture free	18.69	18.51	18.60	18.28
As received MC	17.03	17.38	17.17	17.08
		Joules per gram		
Net calories at constant pressure:				
Moisture free	18,690	18,514	18,605	18,277
As received MC	17,033	17,384	17,168	17,078
Gross calories at constant volume:				
Moisture free	19,968	19,779	19,875	19,551
As received MC	18,402	18,712	18,516	18,419
		British thermal units per pound		
Gross calories at constant volume:				
Moisture free	8,585	8,504	8,545	8,406
As received MC	7,912	8,045	7,961	7,919
PFI grade	Non-standard	Non-standard	Non-standard	Non-standard
Limiting factor(s)	Fines	Fines	Fines	Fines

MC = moisture content, WS = white spruce, and AH = Alaska hemlock.

Table 6—Chemical elements analysis for Alaska hemlock and spruce pellets as reported by Twin Ports Testing, Inc., Superior, Wisconsin

Property	Batch 1 (100% WS)	Batch 2 (67% WS; 33% AH)	Batch 3 (33% WS; 67% AH)	Batch 4 (100% AH)
		Percent		
Tested moisture content	7.84	5.39	6.83	5.79
Carbon:				
Moisture free	51.64	51.31	51.48	51.67
As received MC	47.48	48.45	47.89	48.59
Hydrogen at tested MC:				
Moisture free	5.87	5.81	5.83	5.85
As received MC	5.40	5.49	5.42	5.50
Nitrogen at tested MC:				
Moisture free	0.09	0.09	0.09	0.07
As received MC	0.08	0.08	0.08	0.07
Oxygen at tested MC:				
Moisture free	41.63	41.96	42.04	42.05
As received MC	38.49	39.80	39.26	39.71
Total at tested MC:				
Moisture free	99.23	99.17	99.44	99.64
As received MC	91.45	93.82	92.65	93.87
		Parts per million		
Chlorine as received:				
Moisture free	34	28	11	<10
As received MC	31	26	10	<10

MC = moisture content, WS = white spruce, and AH = Alaska hemlock.

Table 7—Physical properties analysis of Alaska hemlock and spruce pellets as reported by Twin Ports Testing, Inc., Superior, Wisconsin

Property	Batch 1 (100% WS)	Batch 2 (67% WS; 33% AH)	Batch 3 (33% WS; 67% AH)	Batch 4 (100% AH)
		Pounds per cubic foot		
Bulk density	44.29	47.41	46.34	47.21
		Percent		
Sample longer than 1.5 inches	0	0	0	0
		Inches		
Maximum length	0.911	1.364	0.964	1.638
Minimum diameter	0.249	0.248	0.247	0.246
Maximum diameter	0.257	0.250	0.249	0.248
Average diameter	0.254	0.249	0.248	0.247
		Percent		
Fines (by weight)	0.74	0.65	0.55	0.78
Durability index	93.6	96.5	96.7	96.8

WS = white spruce and WH = Alaska hemlock.

Testing and Evaluation

Testing was completed at Twin Ports on February 3, 2010. A summary of chemical properties and energy values are presented in table 5. A complete report of basic chemical elements is included in table 6. Table 7 reports on the physical properties of the samples, including the durability test results.

Discussion of Results

The initial tests resulted in successful formation of pellets, regardless of the mix of raw material. However, a discussion of the results of this experiment is complicated by the fact that changes to the June 18, 2008, PFI grading specifications were approved by the PFI Board on October 7, 2010. Prior to those changes, none of the mixtures produced pellets that could be assigned a PFI grade. But subsequent to those changes, most of the specifications for "premium grade" were met. It should also be noted that the "super premium" grade has been dropped from the new standard.

Bulk Density

The bulk density specification was not changed. For premium grade, a bulk density value between 40.0 and 46.0 lbs/ft^3 is required. For standard and utility grades, the bulk density value is required to be within the range of 38.0 to 46.0 pounds lbs/ft^3. All samples containing hemlock exceeded 46.0 lbs/ft^3, and therefore could not qualify for any PFI grade because the value falls outside the specified limits. Pure spruce had a bulk density value of 44.29, and meets the premium grade specification. Bulk density is an important fuel characteristic, as it affects the fuel-to-air ratio in, and the efficiency of, the pellet-burning appliance. Appliance manufacturers have determined that bulk density values above 46 lbs/ft^3 can detrimentally affect the operation of such appliances. Bulk density is controlled by the "effective length" of the pellet die. A shorter effective length will reduce the bulk density (Wiberg 2010).

The bulk density of hemlock pellets exceeded allowable levels.

Diameter

The old specification for all grades called for diameters to be in the range of 0.250 to 0.285 inch. The new specification calls for diameters to fall within the range of 0.230 to 0.285 inch across all grades. Samples containing hemlock had diameter values of 0.246 to 0.248 inch, 0.247 to 0.249 inch, and 0.248 to 0.250 inch. Pure spruce had a diameter range of 0.249 to 0.257 inch. Under the old specification, pellets containing hemlock could not earn any PFI grade. However, under the new specification, all pellets met the premium grade specification.

Pellet Durability Index (PDI)

For premium grade, the old specification called for a pellet durability index (PDI) value of at least 97.5, whereas the new specifications call for a PDI value of at least 96.5. For standard and utility grades, the PDI must be at least 95.0 (unchanged). The PDI values for samples containing hemlock ranged from 96.5 to 96.8, which did not meet the old premium grade specification (but did meet standard and utility specification). They would, however, meet the new premium grade specification.

Fines

Under the old specifications, "fines" is defined as "the percentage of fuel material in the fuel sample passing through a 1/8-inch screen when the fuel is sampled after completion of production and bagging and before transportation, unloading, distribution, use, etc." (PFI 2008b). Across all grades, the specification for fines was not more than 0.5 percent by weight.

Under the new specifications, "fines" is defined as "the percentage of fuel material in the fuel sample passing through a 1/8-inch screen when the fuel is sampled in accordance with the requirements in 6.1.4." (PFI 2010c). The specification for premium grade calls for a maximum of 0.5 percent by weight (unchanged), and the specification for standard and utility calls for fines not to exceed 1.0 percent by weight.

It is worth noting that the old specification called for a fines determination, essentially "at the mill gate," whereas the new specification calls for a measurement "as delivered."

Fines measurements in this experiment were all determined after transportation and delivery to the testing facility. An accurate determination "at the mill gate" was not made; therefore, no conclusions regarding conformance with the old standard can be made. The results for fines in all samples ranged from 0.55 to 0.78 **as delivered**. None of these measurements would meet the specification for premium grade; however, all would meet the specification for standard and utility grade. At the time of the tests, Alaska Pellet Company did not have any means to remove fines between the pellet storage bin and the bagging machine. It is likely that additional fines could be removed with the installation of an additional screen for that purpose.

Inorganic Ash

The inorganic ash specification was not changed from 2008 to 2010. The specification for premium grade calls for the inorganic ash component not to exceed 1 percent. All samples met the specification.

Length

The length specification was not changed from 2008 to 2010. The specification for premium grade calls for the percentage of pellets longer than 1.50 inches not to exceed 1.0 percent. All samples met the specification.

Moisture

The specification for premium grade was unchanged at 8.0 percent (wb) or less, which all samples met. The specification for standard grade was changed from 8.0 percent or less to 10.0 percent or less. The specification for utility grade was unchanged at 10.0 percent or less.

Chloride

The specification for chloride across all grades remained unchanged at 300 ppm or less. All samples easily met this specification with values ranging from less than 10 to 31 ppm.

Recommendations and Conclusions

In this project, the personnel at Alaska Pellet Company applied the knowledge gained from 2 years of experience producing pellets from white spruce to a new species, Alaska hemlock. Processing procedures and equipment parameters were not changed or modified for the trial runs of the new species. Regardless, the process produced pellets that differed little in visual appearance from those made with the traditional white spruce material. The results of product testing in accordance with PFI standards, however, indicate that the process needs to be fine-tuned to create an Alaska hemlock pellet that fully meets PFI specification.

Slight modifications to material preparation and adjustment to the pellet die should result in hemlock pellets that exceed Pellet Fuel Institute standards.

It is noted that the Alaska Pellet Company had never submitted any samples for laboratory testing and was not aware that pellets were not meeting PFI standards. Furthermore, by relying on results derived from trial and error, the company was unaware of the potential deficiencies caused by particle size being too big or inconsistent, cold feedstock temperatures, or excessively dry feedstock.

Subsequent to these tests, the lower screen on the hammermill was reduced from one with a 0.190-inch mesh to one with a 0.109-inch mesh. It is reported that this has resulted in smaller furnish particle size and a notably visible increase in sheen and apparent increase in pellet hardness.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	25.4	Millimeters (mm)
Inches	2.54	Centimeters (cm)
Cubic feet (ft^3)	.0283	Cubic meters (m^3)
Pounds (lb)	454	Grams (g)
Pounds per cubic foot (lbs/ft^3)	16.02	Kilograms per cubic meter
Tons	.907	Metric tons or Megagrams
Degrees Fahrenheit	.56(°F – 32)	Degrees Celsius (°C)
Btu/lb	0.00064568	Kilowatt hours per kilogram (kWh/kg)
British thermal units (BTU)	1,050	Joules (J)

Literature Cited

Alakangas, E. 2009. Current status of European pellets standardization procedure: EN 145961-1 and EN 14961-2. [PowerPoint presentation] Pellets@LAS Final Workshop. Brussels, Belgium. http://www.pelletsatlas.info/cms/site.aspx?p=9062. (May 13, 2010).

Alakangas, E. 2010. EUBIONET III—New European pellet standard. EN 14961-1. Jyvaskyla, Finland. 9 p. http://www.wsed.at/fileadmin/redakteure/WSED/2010/download_presentations/Alakangas_paper_neu.pdf. (May 6, 2011).

American Lumber Standard Committee, Inc. [ALSC]. 2010. PFI residential/commercial densified fuel enforcement regulations. October 25, 2010. Germantown, MD. http://pelletheat.org/wp-content/uploads/2010/01/ALSC-densified-wood-pellet-fuels-enforcement-regulations-10-25-10.pdf. (October 26, 2010).

American Society of Agricultural and Biological Engineers [ASABE]. 2007. Cubes, pellets, and crumbles—definitions and methods for determining density, durability, and moisture content. ASAE S269.4 DEC1991 (R2007). St. Joseph, MI. 4 p. http://asae.frymulti.com/azdez.asp?JID=2&AID=23569&CID=s2000&T=2. (May 12, 2010).

Brackley, A.M.; Barber, V.A.; Pinkel, C. 2010. Developing estimates of potential demand for renewable wood energy products in Alaska. Gen. Tech. Rep. PNW-GTR- 827. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 31 p.

Brackley, A.M.; Parrent, D.J.; Rojas, T.D. 2006. Estimating sawmill processing capacity for Tongass timber: 2003 and 2004 update. Res. Note PNW-RN-553. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

Bradfield, J.; Levi, M.P. 1984. Effect of species and wood to bark ratio in pelleting of southern woods. Forest Products Journal. 34(1): 61–63.

Chow, S.Z.; Pickles, K.J. 1971. Thermal softening and degradation of wood and bark. Wood and Fiber Science. 3(3): 166–178.

Curran Renewable Energy [CRE]. 2010. Our products. http://www.curranpellets.com/products.html. (May 7, 2010).

EIN Presswire [EIN]. 2010. General Biofuels Canada to build massive wood pellet plant. February 2. http://www.einnews.com/pr-news/70468-general-biofuels-canada-to-build-massive-wood-pellet-plant. (May 7, 2010).

Energy Charter Secretariat [ECS]. 2004. Concluding document of the Hague conference on the European energy charter. http://www.encharter.org/fileadmin/user_upload/document/EN.pdf#page=211. (May 17, 2010).

Energy Charter Secretariat [ECS]. 2010. About the charter. http://www.encharter.org/index.php?id=7&L=0. (May 17, 2010).

Gerber, C.; Gfeller, B. 2000. Joint connection with welded thermoplastic dowels & wood welding technologies. http://timber.ce.wsu.edu/Resources/papers/4-4-1.pdf. (May 14, 2010).

Gfeller, B.; Lehmann, M.; Properzi, M.; Pichelin, F.; Zanetti, M.; Pizzi, A.; Delmotte, L. 2004. Interior wood joints by mechanical fusion welding of wood surfaces. Forest Products Journal. 54(7/8): 72–79.

Hager, H. 2010. Wood pellet standards to be made mandatory—U.S. changes could affect Canadian wood pellet exporters. Canadian Biomass Magazine, October 20, 2010. http://www.canadianbiomassmagazine.ca/content/view/2039/38. (November 2010).

Hahn, B. 2004. Existing guidelines and quality assurance for fuel pellets—pellets for Europe. Deliverable 29. Polten, Austria: Umweltorientierte Betriebsberatungs-Forschungs-und Entsorgungs-Gesellschaft m.b.H. 20 p. http://www.pelletsatlas.info/resources/1020.pdf. (May 12, 2010).

Hatfield, R.D.; Jung, H-J.G.; Ralph, J.; Buxton, D.R.; Weimer, J. 1994. A comparison of the insoluble residues produced by the Klason lignin and acid detergent lignin procedures. Journal of the Science of Food and Agriculture. 65(1): 51–58. http://www.dfrc.wisc.edu/DFRCWebPDFs/1994-Hatfield-JSFA-65-51.pdf. (May 14, 2010).

Irvine, G.M. 1984. The glass transitions of lignin and hemicelluloses and their measurement by differential thermal analysis. Tappi. 67(5): 118–121.

Jonsson, C.Y.C. 2009. Wood fuel pellets—raw material composition, mechanical strength, moisture content, particle size distribution and processing. Skelleftea, Sweden: Lulea University of Technology. 80 p. M.S. thesis. http://epubl.ltu.se/1653-0187/2009/083/LTU-PB-EX-09083-SE.pdf. (May 13, 2010).

Kaliyan, N.; Morey, R.V. 2006. Factors affecting the strength and durability of densified products. Paper No. 066077. 45 p. http://asae.frymulti.com/azdez.asp?JID=5&AID=21754&CID=por2006&T=2. (June 2, 2010).

Kelley, S.S.; Rials, T.G.; Glasser, W.G. 1987. Relaxation behaviour of the amorphous components of wood. Journal of Materials Science. 22: 617–624. http://www.springerlink.com/content/n8xp43jg5v533725/fulltext.pdf. (May 14, 2010).

Leaver, R.H. (n.d.). The pelleting process. Andritz Sprout, Andritz Inc., Muncy, PA; http://www.pdftop.com/ebook/andritz+sprout/. Date accessed October 25, 2010 (Date: Based on the electronic properties section of this .pdf document the report was created and last modified September 23, 2008).

Lehtikangas, P. 2000. Storage effects on pelletized sawdust, logging residues and bark. Biomass and Bioenergy. 19(5): 287–293.

Lehtikangas, P. 2001. Quality properties of pelletized sawdust, logging residues and bark. Biomass and Bioenergy. 20(5): 351–360.

National Institute of Standards and Technology [NIST]. 2010. Voluntary product standard PS 20-10 American softwood lumber standard. Gaithersburg, MD: U.S. Department of Commerce. 50 p.

Nicholls, D.L.; Brackley, A.M.; Barber, V. 2010. Wood energy for residential heating in Alaska: current conditions, attitudes, and expected use. Gen. Tech. Rep. PNW-GTR-826. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.

Nicholls, D.L.; Monserud, R.A.; Dykstra, D.P. 2008. A synthesis of biomass utilization for bioenergy production in the Western United States. Gen. Tech. Rep. PNW-GTR-753. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Nicholls, D.L.; Monserud, R.A.; Dykstra, D.P. 2009. International bioenergy synthesis—lessons learned and opportunities for the Western United States. Forest Ecology and Management. 257(8): 1647–1655.

Niebling, C.; Rockefeller, L.; Ackerly, J.; Conable, D.; Saffron, G.; Henderick, J. 2010. Heating the Northeast with renewable biomass—a vision for 2025. http://www.biomassthermal.org/resource/pdfs/heatne_vision_full.pdf. (May 10, 2010).

Nowacki, G.; Shepard, M.; Krosse, P.; Pawuk, W.; Fisher, G.; Baichtal, J.; Brew, D.; Kissinger, E.; Brock, T. 2001. Ecological subsections of southeast Alaska and neighboring areas of Canada. R10-TP-75. Juneau, AK: U.S. Department of Agriculture, Forest Service, Region 10 [Alaska Region]. 306 p.

Öhman, M.; Boman, C.; Hedman, H.; Nordin, A.; Boström, D. 2004. Slagging tendencies of wood pellet ash during combustion in residential pellet burners. Biomass and Bioenergy. 26: 585–596.

Patton-Mallory, M., ed. 2008. Woody biomass utilization strategy. FS-899. Washington, DC: U.S. Department of Agriculture, Forest Service. 17 p. http://www.fs.fed.us/woodybiomass/strategy/documents/FS_WoodyBiomassStrategy.pdf. (May 7, 2010).

Pellet Fuels Institute [PFI]. 2008a. PFI residential/commercial densified fuel QA/QC handbook. Arlington, VA. 11 p. http://www.pelletheat.org/wp-content/uploads/2010/01/PFI-QA-QC-Hanbook-10-25-20101.pdf. (November 2010).

Pellet Fuels Institute [PFI]. 2008b. PFI standard specification for residential/commercial densified fuel, 18 June 2008. Arlington, VA. 8 p. On file with: Alaska Wood Utilization and Research Center, 204 Siginaka Way, Sitka, AK 99835.

Pellet Fuels Institute [PFI]. 2010a. PFI Board approves standards program. http://pelletheat.org/wp-content/uploads/2010/10/pfi-board-approves-standards-program.pdf. (November 2010).

Pellet Fuels Institute [PFI]. 2010b. PFI standard specification for residential/commercial densified fuel. http://pelletheat.org/wp-content/uploads/2010/08/Draft-PFI-StandardSpecification-for-Residential-Commercial-Densified-Fuel-Revised-June-23-2010.pdf. (October 25, 2010). Superseded by http://pelletheat.org/wp-content/i[;pads/2010/01/PFI-Standard-Specification-for- Residential-Commercial-Densified-Fuel-10-25-10.pdf. (November 2010). Copies of the October 25, 2010, version are on file with: Alaska Wood Utilization and Research Center, 204 Siginaka Way, Sitka, AK. 99835.

Pellet Fuels Institute [PFI]. 2010c. What are the PFI standards? http://pelletheat.org/pfi-standards/what-are-the-pfi-standards/. (October 25, 2010).

Perlack, R.D.; Wright, L.L.; Turhollow, A.F.; Graham, R.L.; Stokes, B.J.; Erbach, D.C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge, TN: Oak Ridge National Laboratory. 78 p.

Peska-Blanchard, M.; Dolzan, P.; Grassi, A.; Heinimo, J.; Junginger, M.; Ranta, T.; Walter, A. 2007. Global wood pellets market and industry: policy drivers, market status, and raw material potential. IEA Bioenergy Task 40. Paris, France. 120 p. http://www.bioenergytrade.org/downloads/ieatask40pelletandrawmaterialstudynov2007final.pdf. (May 12, 2010).

Pizzi, A.; Leban, J.M.; Kanazawa, M. 2004. Wood dowel bonding by high-speed rotation welding. Journal of Adhesion Science and Technology. 18(11): 1263–1278.

Pizzi, A.; Properzi, M.; Leban, J-M.; Zantii, M.; Pichelin, F. 2003. Mechanically induced wood welding. Maderas. Ciencia y tecnologia. 5(2): 101–106. http://www.scielo.cl/scielo.php?pid=S0718-221X2003000200001&script=sci_arttext. (May 14, 2010).

PR.com. 2009. Sweden consumes more than 20% of the world's wood pellets and demand is growing, reports the Wood Resource Quarterly. http://www.pr.com/press-release/177995. (May 10, 2010).

Sastry, K.V.S.; Fuerstenau, D.W. 1973. Mechanisms of agglomerate growth in green pelletization. Powder Technology. 7(2): 97–105.

Sokhansanj, S.; Mani, S.; Bi, X.; Zaini, P.; Tabil, L. 2005. Binderless pelletization of biomass. Presentation: American Society of Agricultural and Biological Engineers, Annual International Meeting, Tampa, FL. 15 p. http://asae.frymulti.com/azdez.asp?search=1&JID=5&AID=19922&CID=tfl2005&T=2. (May 7, 2010).

Spelter, H.; Toth, D. 2009. North America's wood pellet sector. Res. Pap. FPL-RP-656. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 21 p.

Stahl, M.; Granston, K.; Berghel, J.; Renstrom, R. 2004. Industrial process for biomass drying and their effects on the quality properties of wood pellets. Biomass and Bioenergy. 27(6): 621–628.

Szczesniak. L.; Rachocki, A.; Tritt-Groc, J. 2008. Glass transition temperature and thermal decomposition of cellulose powder. Cellulose. 15: 445–451.

Temmerman, M.; Rabier, F.; Jensen, P.D.; Hartmann, H.; Bohm, T. 2006. Comparative study of durability test methods for pellets and briquettes. Biomass and Bioenergy. 30(11): 964–972.

Tongass Futures Roundtable [TFRT]. 2008. Future harvest level capacity of second rotation forests preliminary draft progress report. http://www.tongassfutures.net/docs/microsoft-word-december-report.pdf. (April 9, 2010).

Tumuluru, J.S.; Wright, C.T.; Kenney, K.L.; Hess, J.R. 2010. A technical review on biomass processing: densification, preprocessing, modeling, and optimization. INL/CON-10-18636 Preprint, Idaho Falls, ID: U.S. Department of Energy, Idaho National Laboratory. 32 p. http://www.inl.gov/technicalpublications/Documents/4559449.pdf. (November 2010).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2008. Tongass National Forest: land and resource management plan. R10-MB-603B. Juneau, AK: Alaska Region. 468 p.

van Hees, W.W.S. 2003. Forest resources of Southeast Alaska, 2000: results of a single-phase systematic sample. Res. Pap. PNW-RP-557. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 96 p.

Wiberg, C. 2010. Personal communication. Chief operations officer, Twin Ports Testing, Superior, WI.

Wilson, T.O. 2010. Factors affecting wood pellet durability. State College, PA: Pennsylvania State University, Department of Agricultural and Biological Engineering. 77 p. M.S. thesis.

Wood, J.F. 1987. The functional properties of feed raw materials and their effect on the production and quality of feed pellets. Animal Feed Science and Technology. 18(1): 1–17.

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Pacific Northwest Research Station
333 SW First Avenue
P.O. Box 3890
Portland, OR 97208-3890