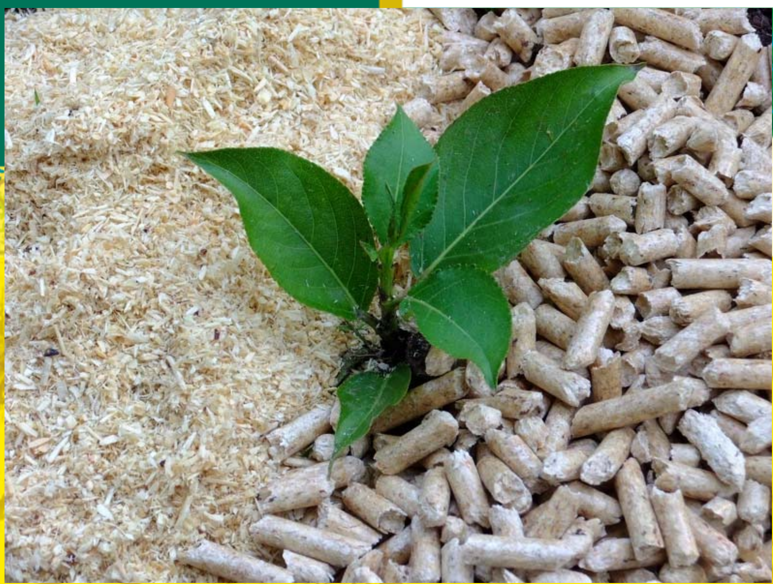
Margin potential for a long-term sustainable wood pellet supply chain

Annexes



IEA Bioenergy

IEA Bioenergy Task 40: 5/2019 - Annexes

Margin potential for a long-term sustainable wood pellet supply chain - Annexes

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IEA Bioenergy Task 40

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Published by IEA Bioenergy

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1 Annex 1: Pellet supply chain - detailed inputs to chapter 2 of the main report

Ric Hoefnagels, Utrecht University; Fabian Schipfer, EEG TU Vienna & Michael Wild, Wild & Partner

1.1 Pellet production

The cost estimates summarized in Table 1 are based on Obernberger & Thek (2010) and calculated to scale using the following equation:

$$Inv = Inv_{ref} * (P / P_{ref})^{0.82}$$

- Inv_{ref}: Investment cost of the reference plant size
- Inv: Investment cost of the plant size
- P_{ref}: pellet production capacity of the reference plant
- P: pellet production capacity of the plant

A conservative scale factor of 0.82 for investment cost is assumed because many components in a pellet production plant, such as including hammer mills and pellet mills, do not scale well and need to be installed in trains. In contrast, labor requirements generally decrease more rapidly per unit output at larger scales. Similar to Patel et al. (2006) we assumed a scale factor of 0.25 to calculate labor requirements at larger scale. Investment cost were annualized using the capital recovery factor (CRF) based on the lifetime (L) of the pellet plant (17.5 years) and a discount rate of 7%.

Table 1 Costs and other input data for the pellet plants

Parameter	Unit	Pellets from wood chips/pulp-grade stemwood Latvia	Pellets from wood chips/pulp-grade stemwood US SE[b]	Pellets from sawmill residues Latvia	Pellets from sawmill residues US SE[b]	Pellets from bagasse Brazil[c]
Annual production	t/a	120,000	400,000	120,000	400,000	120,000
Production rate	t/h	15	50	15	50	15
Annual operating hours	h	8000	8000	8000	8000	8000
Lifetime	years	17.5	17.5	17.5	17.5	17.5
Total investment[a]	M$	11.84	31.63	9.64	25.76	9.64
OPEX						
Replacement parts, consumables	$/t pellets	4.50	4.50	4.50	4.50	4.50
Service, maintenance and other cost	% of investment cost /year	6.2%	6.2%	6.2%	6.2%	6.2%
Labor requirement	FTE	5.75	7.77	5.75	7.77	5.75
	h/yr	16790	22687	16790	22687	16790
	hr/t output	0.140	0.057	0.140	0.057	0.140
Simultaneity factor for electric consumptions		0.85	0.85	0.85	0.85	0.85
Energy, electric	kW	1,874	1,027	1,027	1,588	1,588
	MWh/yr	12,744	6,984	6,984	10,800	10,800
	kWh/t output	106.2	106.2	58.2	58.2	90
Energy, thermal	kWh/tev.w.	1100	1100	1100	1100	1100
Boiler efficiency		85%	85%	85%	85%	85%

a) The Chemical Engineering Plant Cost Index (CEPCI) was used to update cost from €$_{2008}$ as published in Obernberger & Thek (2010) to €$_{2017}$ and converted to $$_{2017}$

b) A scale factor of 0.82 was assumed to calculate CAPEX cost for larger pellet mills (Obernberger & Thek 2010). A scale factor of 0.25 was assumed to calculate labor requirements (Patel et al. 2006)

c) Pellets from bagasse are assumed to be designed similar to a pellet mill using sawmill residues

Source: own compilation

1.2 Transportation

Road transportation cost in Table 2 are calculated at 1.22 – 1.69 $/km based on BioBoost (Rotter & Rohrhofer 2014). The lower average speed in Brazil reflects the limitations of available road infrastructure. Cost are however highest in the US, resulting from higher labor cost compared to Latvia and Brazil.

Table 2 Road transportation cost

	Unit	Region		
		Georgia (US)	Latvia	Brazil (Sao Paulo)
Labor cost	$/h	39.0	11.9	8.1
	$/km	0.71	0.22	0.27
Kilometer rate (excl. fuel/labor cost)	$/km	0.64	0.64	0.64
Fuel consumption	l/km	0.37	0.39	0.70
Fuel cost	$/km	0.34	0.36	0.65
Empty return		Yes	Yes	Yes
Load by weight	t	27	27	30
Speed (average)	km/h	55	55	30
Loading/unloading cost	$/t	4.8	4.8	4.8

Source: own compilation

Table 3 Bulk carrier classes and their main characteristics

Parameter	Unit	Bulk carrier class	
		Handysize	Supramax
Deadweight tonnes (DWT)	t	28000	57000
Cargo Capacity	t	26000	54000
Total displacement when under ballast	t	16600	29650
Ballast	t	7000	14250
Total displacement when fully loaded	t	36000	70000
Hold volume for cargo	m^3	34667	72000
Speed	km/h	27	27
Fuel consumption at full load	kg HFO /km	43.5	58.9
Fuel consumption when empty (at ballast)	kg HFO /km	33.6	44.2
Empty trip factor*		0.43	0.43

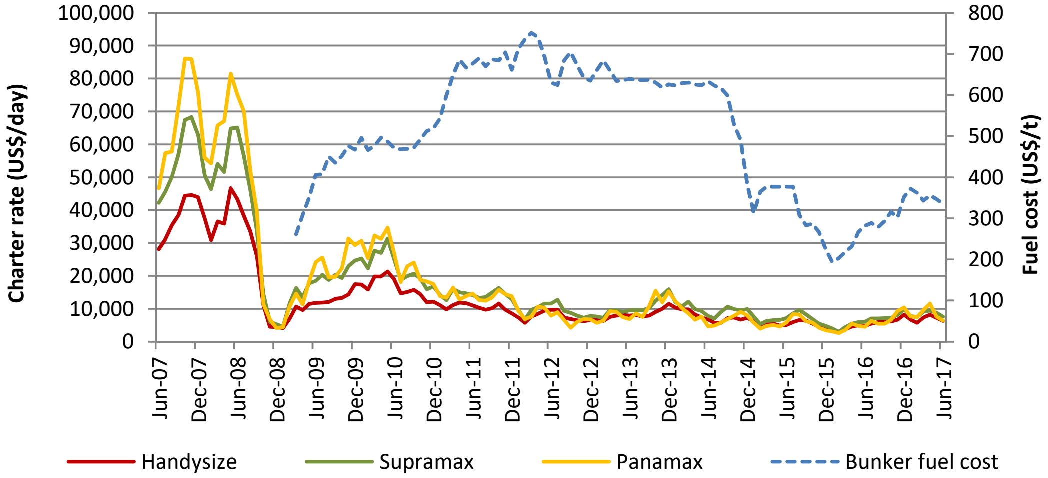
*) Distance empty/total distance

Source: Giuntoli et al. (2015)

Average daily rates in 2016 for Handysize and Supramax dry bulk carriers were 5262 $/day and 6288 $/day, respectively. These charter rates reflect continuously poor market conditions, the oversupply of ships and weak demand (UNCAD 2017) that resulted in record low freight rates in 2016.

Although not shown in the graph in Figure 1, daily rates are currently improving as a result of economic growth.

Figure 1 Daily earnings of dry bulk carrier vessels



Source: UNCAD (2017) and development of the average global bunker price (AGBP) for 380 CST (centistoke) bunker fuel prices as reported to Bunker Index (Bunker Index 2018)

In the period 2009 – 2018, the average global bunker fuel price (380 CST) peaked in March 2012 at 760 $/t and were at its lowest in January 2016 (188 $/t).

Similar to crude oil prices, marine fuel prices are increasing again. We assumed average prices over the years 2016 -2017 to calculate ocean shipping cost at 316 $/t.

1.3 Cost and ranges of Interregional wood pellet supply chains

Table 4 Cost ranges of interregional supply chains of white wood pellets (WWP)

	Bulk big, vessel industrial	Bulk big, vessel heat	Bulk big, train ind. /heat	Bulk small, container heat	Bulk small, truck heat	bagged, container heat	bagged, truck heat	cost factor	technical/quality risk	organisational risk	cost reduction (limitation) potential by supplier
Interregional supply chain WWP	Range	Range	Range	Range	Range	Range	Range				
Storage at producer								x			x
Loading at producer								x	x		
Weight determination								x			
Transport to port	4 - 14			20 - 40		20 - 40		x			x
Storage at port								x	x		x
Quality&safety management at port	0 - 1							x			x
Loading to vessel	3 - 10							x	x		x
Vessel demurrage/port congestion	-1 - 5							x			x
Documentation costs&agency fees	0.1 - 0.5			2 - 6		2 - 6		x			
Loading volume shortage										x	
Sloppy stowage										x	
Loaded weight determination	0.1 - 0.3							x	x		
Loaded quality determination	0.1 - 0.1							x	x	x	
Shipping incl. eventual dockage dues	10 - 35			30 - 50		30 - 50		x			x
TSCTHC, inspection,collection/return				15 - 30		15 30		x			
Vessel demurrage/port congestion	-1 - 5							x			x
Unloading resp container handling	3 - 10			3 - 3		3 - 3		x	x		x
Loaded weight determination	0.1 - 0.3				0.1 0.1		0.1 - 0.1	x			
Loaded quality determination	0.1 - 0.1							x			
Transloading to final transporter barge	3 - 6							x	x		x
Barging to customer inland port	4 - 10	15 - 20									
Unloading	5 - 8										
Warehousing at port or loading station		5 - 5	5 - 5			0 - 5	0 - 5	x	x		x
Restacking/repalleting		3 - 3				15 - 40		x	x		x
Quality&safety management at port or loading statio	0.0 - 0.5		1 - 1					x			
Loading to transporter train/elevator			1 - 2				10 - 50	x	x		
Loading to transporter truck	1 - 2	1 - 2		2 - 4				x			
Exchange rate										x	x
Transport limitation variations final transporter								x	x	x	x

Source: Compilation and calculations by Michael Wild

Table 5 Cost ranges of regional distribution of white wood pellets (WWP)

	Bulk big, vessel industrial	Bulk big, vessel heat	Bulk big, train ind. /heat	Bulk small, container heat	Bulk small, truck heat	bagged, container heat	bagged, truck heat	cost factor	technical/q uality risk	organisatio nal risk	cost reduction (limitation) potential by supplier
Reginal Distribution systems WWP											
Pick up at producer								x			
Interim (seasonal) storage					15 - 15			x			
Screening/manipulation					4 - 12			x			
Packing+palette								x			
Delivery to customer warehouse (DIY)						5 - 15	5 - 16	x			
Distribution by blower truck					23 - 33			x			
US$/mt, costs in blue will in most cases appear in local currency different to US$, here converted at 1,1US$/€											

Source: Compilation and calculations by Michael Wild

1.4 References for Annex 1

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2 Annex 2: Pellet production technology improvements – details om Chapter 3.1

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2.1 Biomass density limitations

Agricultural straws and woody biomass are low in density which creates problems for handling and transportation. Low biomass densities result in high transportation costs. Densification of biomass helps to overcome these density limitations. Densification refers to the compression of the loose biomass into a pellet, briquette, cube, or others using mechanical systems.

Tumuluru et al. (2011) indicated that densification reduces the moisture content and the volume of the biomass, thus making it more suitable for long-term storage and transportation. Another advantage of densification is it converts biomass into commodity type products for different end-use applications.

The major advantages of densification are

(1) improves the handling and conveyance of biomass throughout the supply system and biorefinery infeed;

(2) consistent particle size distribution;

(3) improved compositional quality; and

(4) meeting the quality requirements for the conversion technology and supply system specifications.

Common biomass densification systems that are commonly used for biomass densification are pellet mills, cubers, and briquette presses (Tumuluru et al. 2011).

Pellet mills produce densified products that are cylindrical with typical dimensions of length and diameter (i.e., 13–19 mm and 6.3–6.4 mm and bulk densities of 600-700 kg/m^3).

Pellets are the most commonly used densified products for bioenergy production. Pellet quality plays a major role in handling, storage, and transportation properties.

2.2 Conventional pellet production process

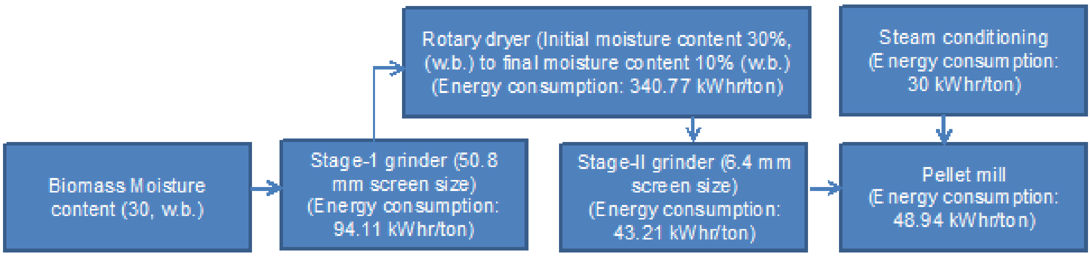
Searcy et al. (2015) in their report on validation of advanced feedstock supply system indicated that one of the major limitations in using high moisture woody and herbaceous biomass by biorefineries for biofuels production is high preprocessing (size reduction, drying, and densification) costs. Pre-processing takes about 33-35% of the total feedstock cost.

Fig 1 indicates the unit operations associated with the conventional pelleting process. In this process, the high-moisture woody and herbaceous biomass, typically at 30% (w.b.), is conveyed through a stage-1 grinder, which is typically a horizontal hammer mill fitted with a screen size in the range of 25.4-50.8 mm (Yancey et al., 2013).

The stage-1 milled biomass is further sent to a rotary dryer where it is dried to 10% (w.b.) moisture content. The dried biomass is further sent to stage-2 grinder fitted with either 4.8 or 6.4 mm screen and is further pelletized using steam (Fig. 2).

Lamers et al. (2015) study on understanding the cost of pelleting indicated that unit operations performance regarding energy consumption, throughput, and capital cost play a major role on the cost of the pellets produced. These authors indicated that in conventional pelleting drying takes about 65-70 % of the total energy.

Figure 2 Conventional pelleting process



Source: Tumuluru (2016)

Tumuluru et al. (2014) in studies indicated that efficient moisture management is critical for reducing the preprocessing costs of biomass. Sakkampang & Wongwuttanasatian (2014) indicate that in the production of the glycerin-biomass briquettes drying takes about 2.25 MJ/kg, whereas briquetting takes about 0.05–0.10 MJ/kg for different feedstocks (sawdust, sugarcane bagasse, sugarcane leaf, and rice husk). According to Yancey et al. (2013), the type of the biomass also has a major impact on the cost of pelleting. Their study indicated that lodgepole biomass, it takes about 350 kWh/ton to dry biomass from 30 to 10% (w.b.) moisture content, and eucalyptus takes about 401 kWh/ton, whereas pelleting lodgepole pine takes about 48.94 kWh/ton and eucalyptus takes about 125 kWh/ton. According to Pirraglia et al. (2010), pelleting takes about 9% of the total energy whereas rotary dryers take about 70 %.

The major limitation of drying of biomass using high-temperature dryers such as rotary dryers is the emission of volatile organic emissions. According to Granström (2005) and Johansson & Rasmuson (1998), studies indicated that drying of woody biomass results in emissions of volatile organic compounds (VOC) that are a serious concern for humans and as well as environment. These VOC form photooxidants which are harmful to humans if they inhale, and will also disturb photosynthesis, causing damage to forests and crops.

2.3 High moisture pellet production

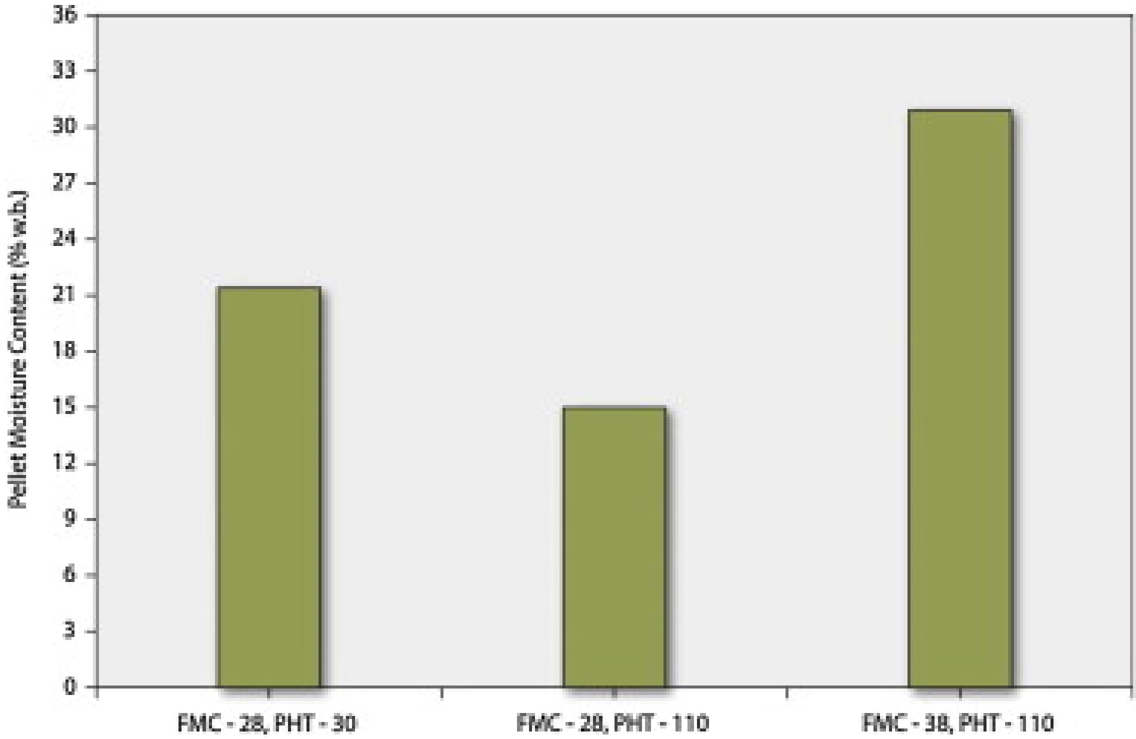
Idaho National Laboratory has developed a high moisture pelleting process which helps to reduce the drying cost and makes pelleting more cost-effective. The high-moisture pelleting process replaces rotary dryer in the front end with a grain or belt dryer at the back end of pelleting. In this process, the steam conditioning is replaced with short preheating step. Biomass is pelleted at high moisture content, and the high moisture pellets are further dried in low-temperature dryers such as grain and belt dryers. Also, the major advantage of using grain or belt dryers is they are less capital intensive. High moisture pelleting studies were conducted on woody, herbaceous and chemically pretreated biomass at moisture contents >20% (w.b.) (Hoover et al. 2014, Tumuluru 2014-2018, Tumuluru et al. 2016, Bonner et al. 2016).

Pelleting tests were conducted both on a flat die laboratory scale pellet mill and ring die pilot scale pellet mill. Also, another major advantage of the process is during pelleting some of the moisture in the biomass is lost due to preheating and frictional heat developed in the die during compression and extrusion.

Tumuluru (2014-2018) and Tumuluru et al. (2016) observed about 8-10 % moisture loss in the biomass during pelleting, where the high moisture pellets produced can be further dried in low temperature dryers such as grain or belt dryers which operate at moisture content of <80°. Figures 3 and 4 indicate the moisture loss in woody and herbaceous biomass during high moisture pelleting.

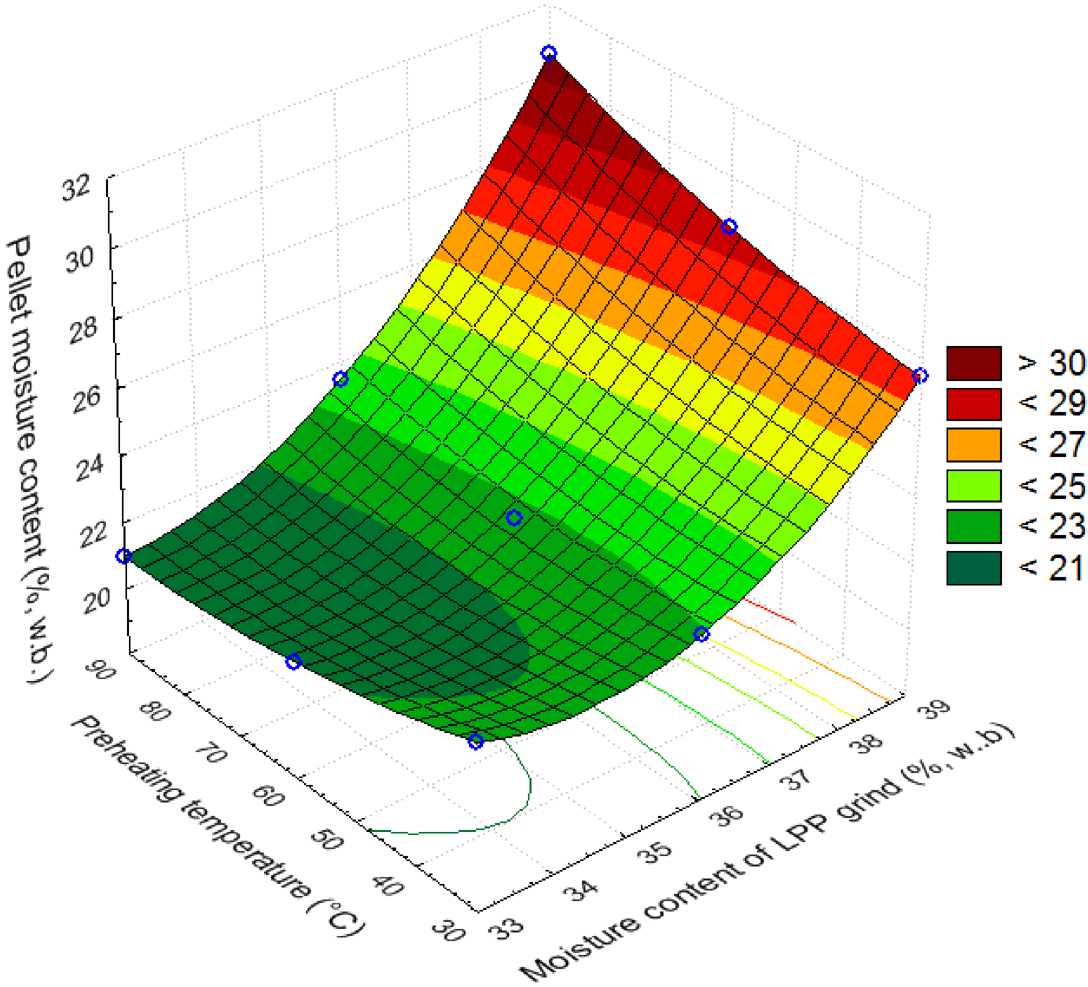
According to Hellevang (2013), grind dryers can operate between 32-90°C and drying temperature is selected based on the material to be dried and the initial moisture of the product. Lamers et al. (2015) techno-economic analysis indicated that the cost to produce pellets using high moisture pelleting process is about 40% less compared to the conventional method followed by the industry.

Figure 3 Moisture loss in corn stover during high moisture pelleting



Source: Tumuluru (2014)

Figure 4 Moisture loss in lodgepole pine during high moisture pelleting



Source: Tumuluru (2016)

2.4 Quality of high moisture pellets

Studies conducted by Tumuluru (2014, 2015, and 2016) and Tumuluru et al. (2016) has indicated that both woody and herbaceous biomass can be pelleted at high moisture contents. These authors tested high moisture pelleting process in a flat die pellet mill and found that the moisture content, preheating temperatures, the rotational speed of the die has a significant impact on the quality of the pellets produced. These authors also indicated that bulk density and durability are also influenced by the pelleting process conditions such as the initial moisture content of the feedstock, preheating temperature and die rotational speed (Figs 4-6). It is very clear from the figures that the quality of the pellets in terms of density and durability decreases with increase in moisture content.

The lowest bulk density of about <388 kg/m3 was observed when lodgepole pine when pelleted at about 39% (w.b.)/ Also the durability of both woody and herbaceous biomass is influenced by moisture content.

Figure 5 Bulk density changes with respect to process conditions for lodgepole pine biomass

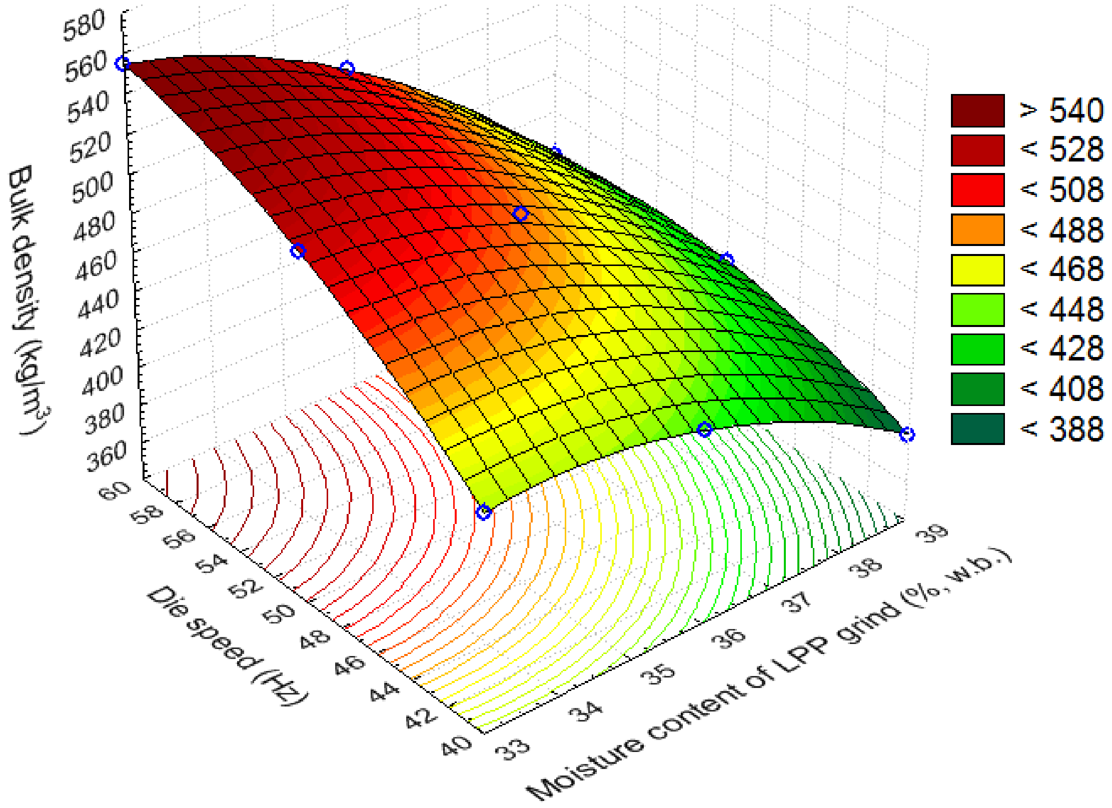
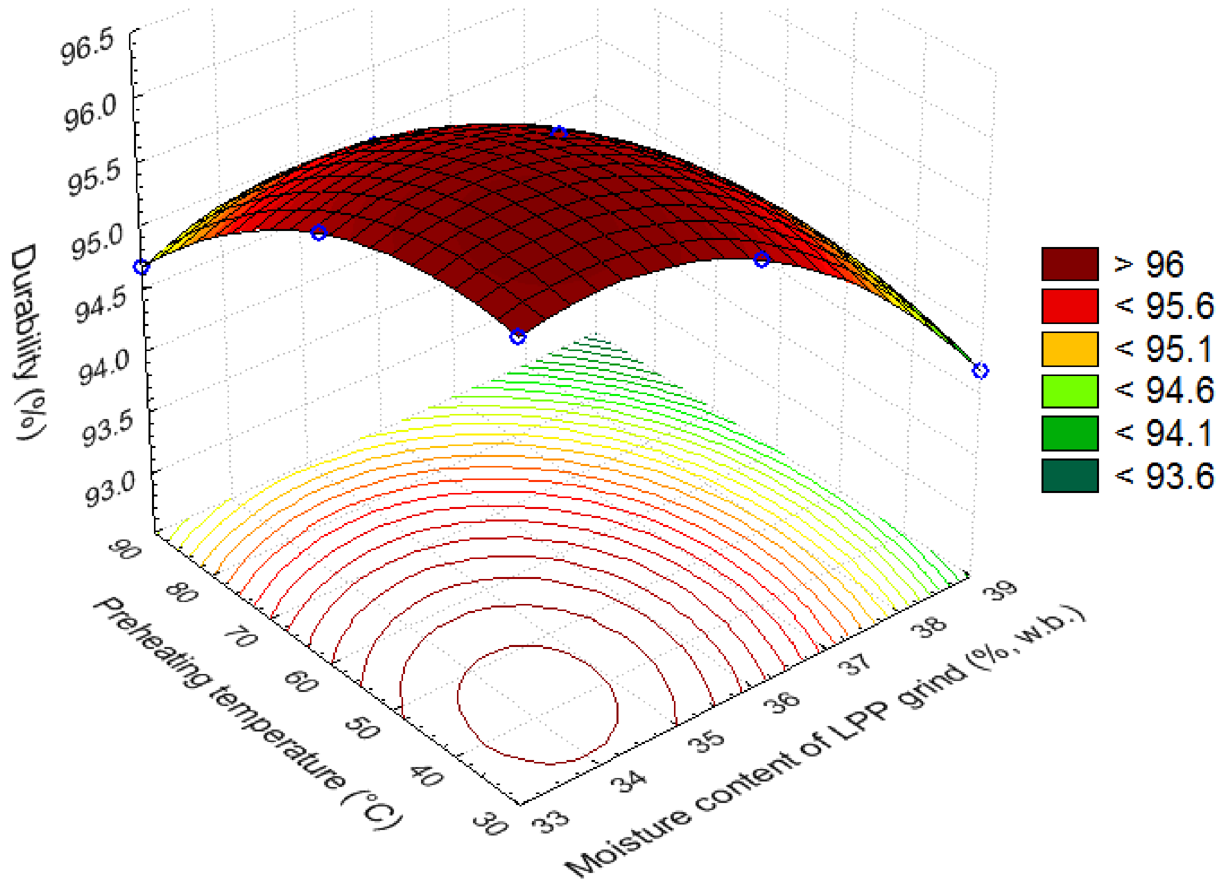


Figure 6 Lodgepole pine pellet durability with respect to pelleting process conditions



2.5 Glass transition studies on high moisture biomass

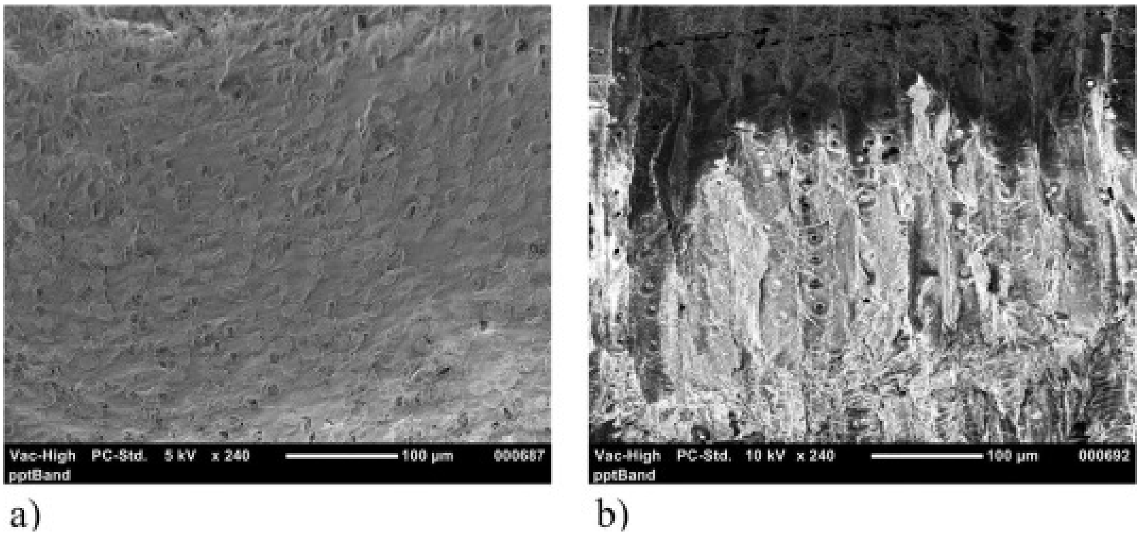
Lignin is considered as a basic binding agent for both woody and herbaceous biomass to form pellets (Tumuluru 2018). Lignin under glass transition temperature (Tg), acts as a brittle material (Tumuluru 2018), whereas above the Tg, lignin acts as a viscous material. Once the lignin gets cooled it re-solidifies, and add strength to the densified biomass.

There are other biomass components such as protein, waxes, and carbohydrates which changes Tg in the presence of temperature, moisture, and pressure (Tumuluru 2018).

So the pellets that are formed below the glass transition temperature result in pellets with lower durability. Tumuluru (2014 + 2018) reasoned that the binding of biomass during pelleting could be due to changes in glass transition temperature of biomass components such as lignin, waxes, protein, and others.

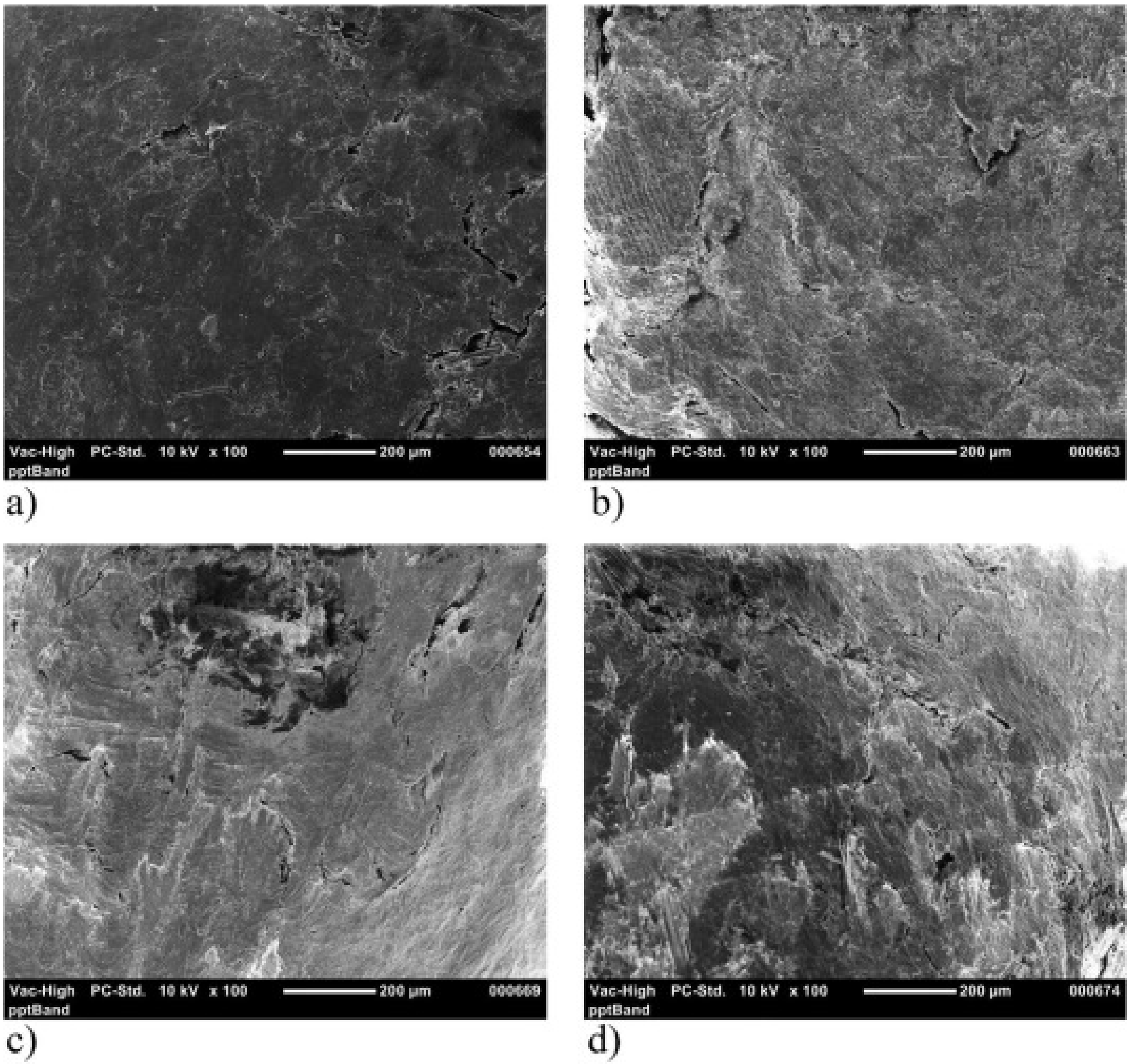
Tumuluru (2018) studied changes in the lignin during densification using scanning electron microscope, indicating that the structure is more random in raw biomass whereas in the case of densified biomass structure is much more organized with holes and cross-threads appearing in rows or columns (Figures 7 and 8). Also, the SEM figures indicated that lignin was distributed as tiny globules or fractions indicating that the lignin was melted and spread out during the densification process.

Figure 7 Scanning electron study of raw corn stover and lodgepole pine



Source: Tumuluru (2018)

Figure 8 Scanning electron microscope photographs of (a) an 8 mm corn stover pellet; (b) a 10 mm corn stover pellet; (c) an 8 mm lodgepole pine pellet; and (d) a 10 mm lodgepole pine pellet



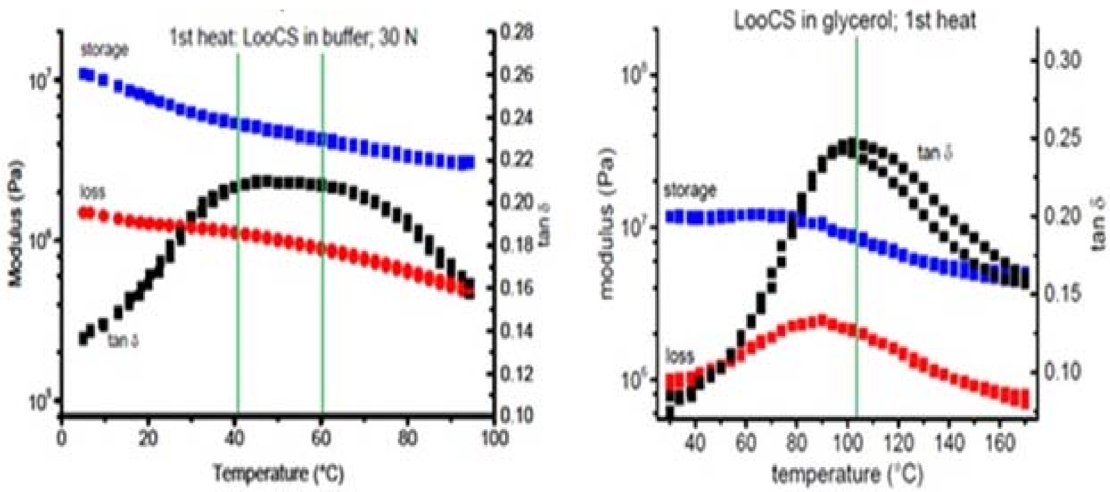
Source: Tumuluru (2018)

Tumuluru et al. (2017) used dynamic mechanical analysis (DMA) and solid-state nuclear magnetic resonance (NMR) to understand the impact of moisture on the Tg of corn stover biomass components (Fig. 9). The DMA results indicated that thermal transitions in corn stover components defined by peaks in the tan δ curve for high moisture (about 30%, w.b.) occur at temperatures of ~40–60 °C whereas at lower moisture content occur at about 105°C.

The thermal transition that happens in the biomass components at higher moisture content can aid in the densification process. Solid state-NMR studies conducted by the same authors (Tumuluru et al., 2017) also indicated that the dipolar de-phased spectrum of wet biomass showed xylans and lignin as the mobile components (Fig. 10).

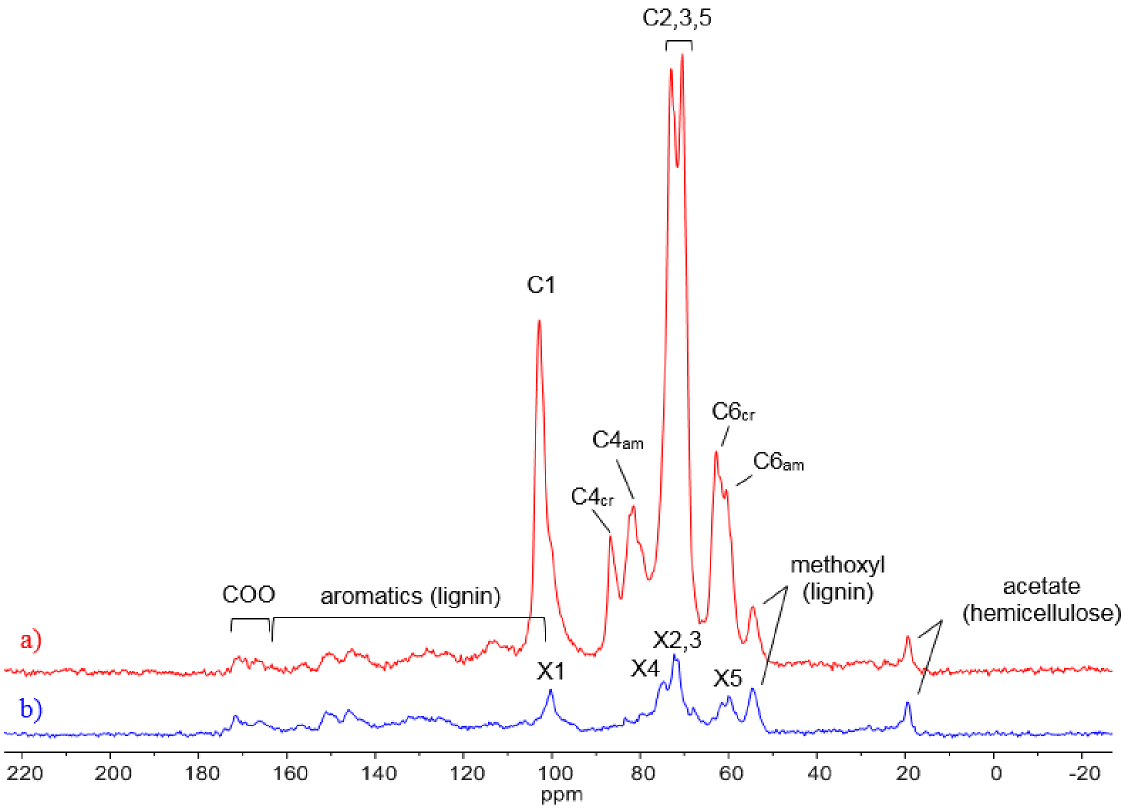
^{13}C spin-lattice relaxation rate constants show hemicellulose, while lignin molecules mobility increased in the presence of water (Table 6).

Figure 9 Compression-torsion DMA of ground corn stover



Source: Tumuluru et al. (2017); immersed in aqueous buffer @ pH 7 (left), and in glycerol (right). Thermal transitions are defined by peaks in the tan δ curve (tan δ = loss modulus ÷ storage modulus)

Figure 10 Solid state-NMR spectrum



Source: Tumuluru et al. (2017)

Table 6 ^{13}C T_1 mobile component relaxation rate constants

	Chemical shift (ppm)				
	72.7 (HC)	70.4 (HC)	62.8 (HC)	53.6 (LI)	19 (HC)
Dry Corn Stover	12 s	12 s	4.2 s	3.0 s	10 s
Wet Corn Stover	4.5 s	4.6 s	1.6 s	2.3 s	6.5 s
Note: HC: Hemicellulose; LI: lignin					

Source: Tumuluru et al. (2017)

2.6 High moisture pelleting tests in a pilot scale pellet mill

High moisture pelleting tests on corn stover were conducted in a pilot scale ring die pellet mill with a throughput of 1 ton/hr. The studies indicated that the quality of the pellets decreases with increase in moisture content (Tumuluru et al. 2017).

The moisture loss observed were similar to lab-scale studies. There is about 10% moisture loss in the corn stover when pelleted at 30% (w.b.) moisture content (Fig 11). The bulk and durability values also decreased with an increase in moisture of the corn stover grind (Figs. 12 and 13). In case of durability, both green durability and cured durability were measured.

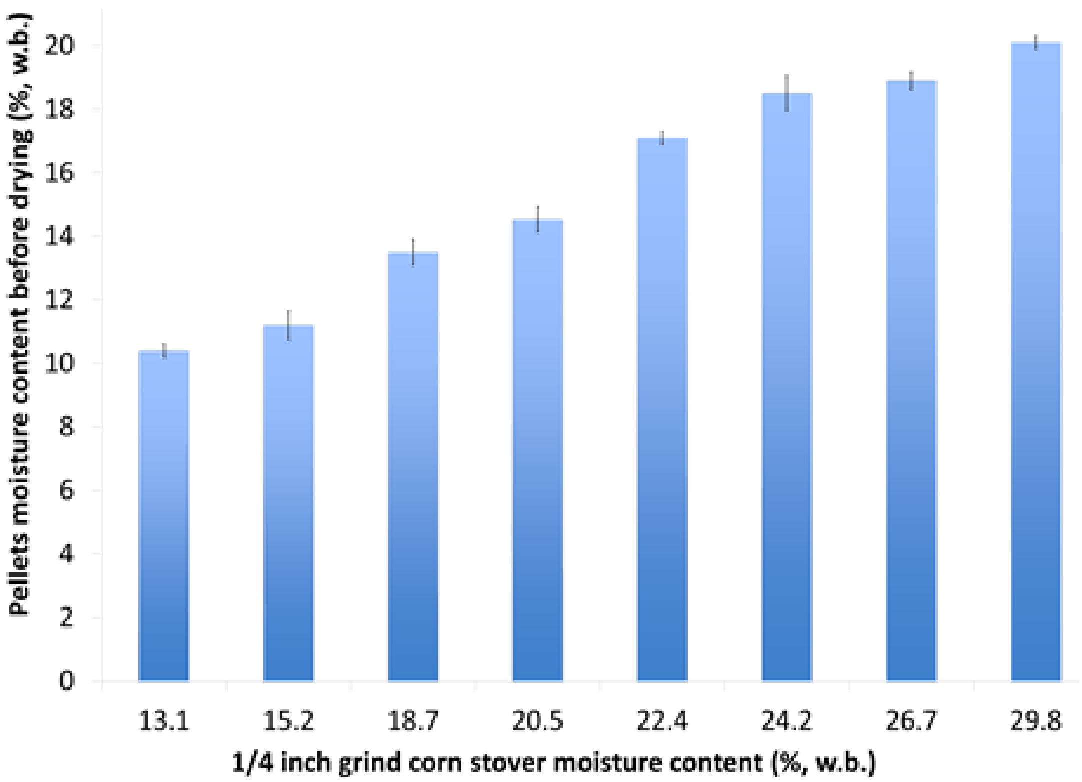
Green durability is the durability of the wet pellets whereas the cured durability is the durability of the pellets after drying at low temperatures. For all the pelleting conditions tested the cured durability is higher than green durability. Tests indicated that drying the high moisture pellets has helped to improve the durability values.

The durability data indicated that up to 25 % the durability values were >95% (w.b.), going to 27 and 30% (w.b.) moisture content reduced the durability values to <95%. The pelleting energy consumption data also indicated that it increased with increase in moisture content (Fig. 14). Fig 15 indicates the photographs of corn stover pellets made at high moisture contents.

In 2017, high moisture pelleting tests were conducted on ring die commercial scale pellet mill with 5 ton/h throughput at INL. The trends have matched with what we have observed for data we have obtained using ring die pilot scale 1 ton/h pellet mill.

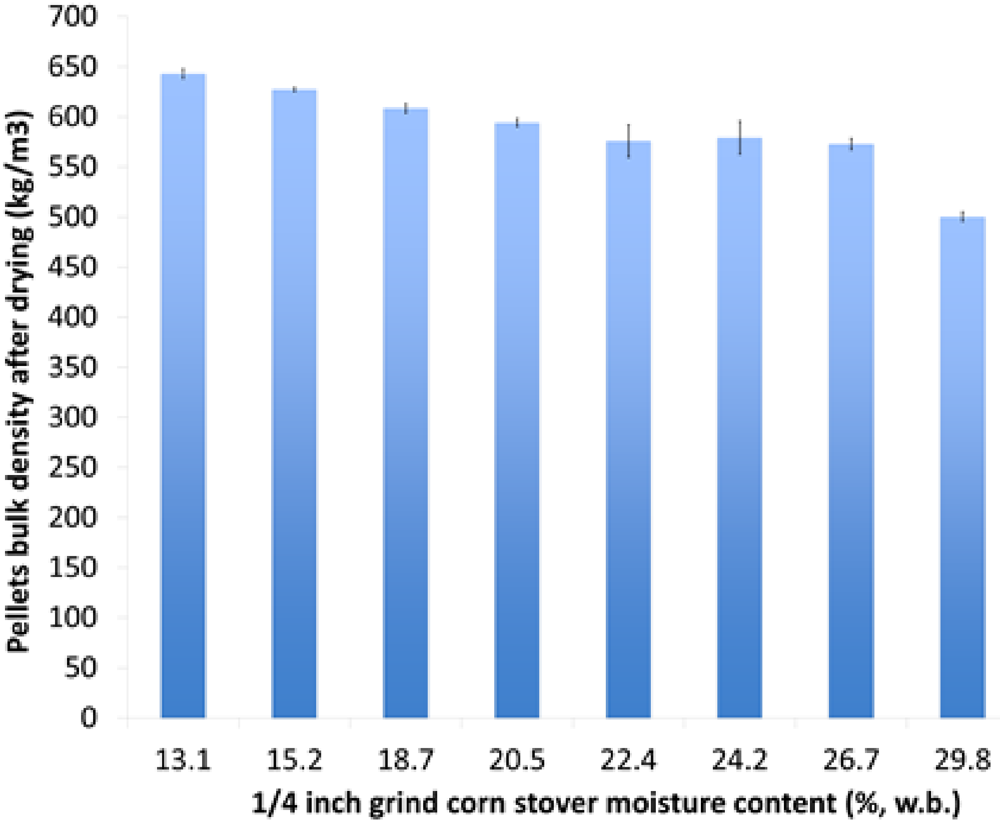
The corn stover bales at 25-27% (w.b.) moisture content were processed through stage-1 and stage-2 grinding and were further pelleted without drying. The quality of the pellets produced were >630 kg/m3 and durability was >97.5 %. Also these studies has indicated that changing the screen size in stage-2 grinder from 1/4-inch (6.35 mm) to 7/16-inch (11.11mm) did not significantly influence the bulk density and durability values of the corn stover pellets produced but lowered stage-2 grinder energy consumption significantly. The increase in pelleting energy by going to bigger screen size in stage-2 grinder was marginal.

Figure 11 Moisture loss in corn stover grind when pelleted at different moisture content



Source: Tumuluru et al. (2017)

Figure 12 Pellet bulk density at different corn stover grind moisture content



Source: Tumuluru et al. (2017)

Figure 13 Impact of corn stover moisture content on green and cured durability

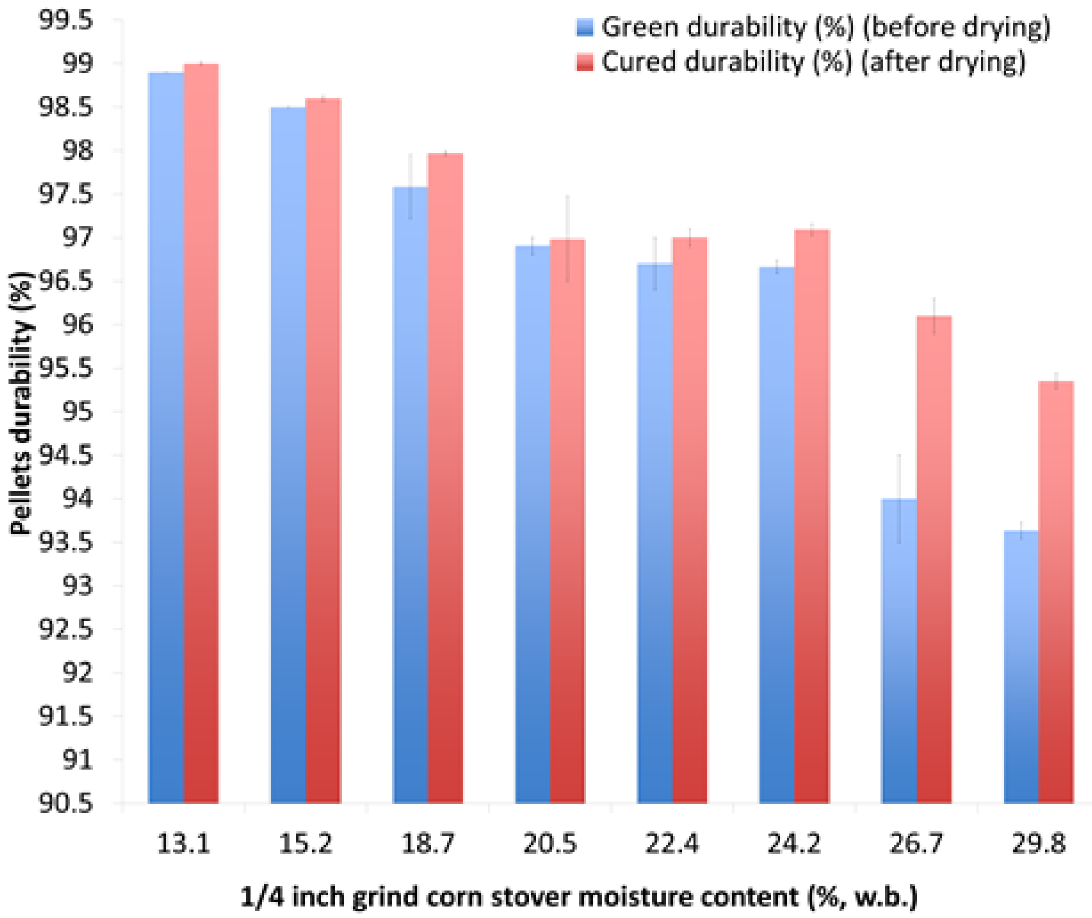


Figure 14 Pelleting energy at different corn stover grind moisture content

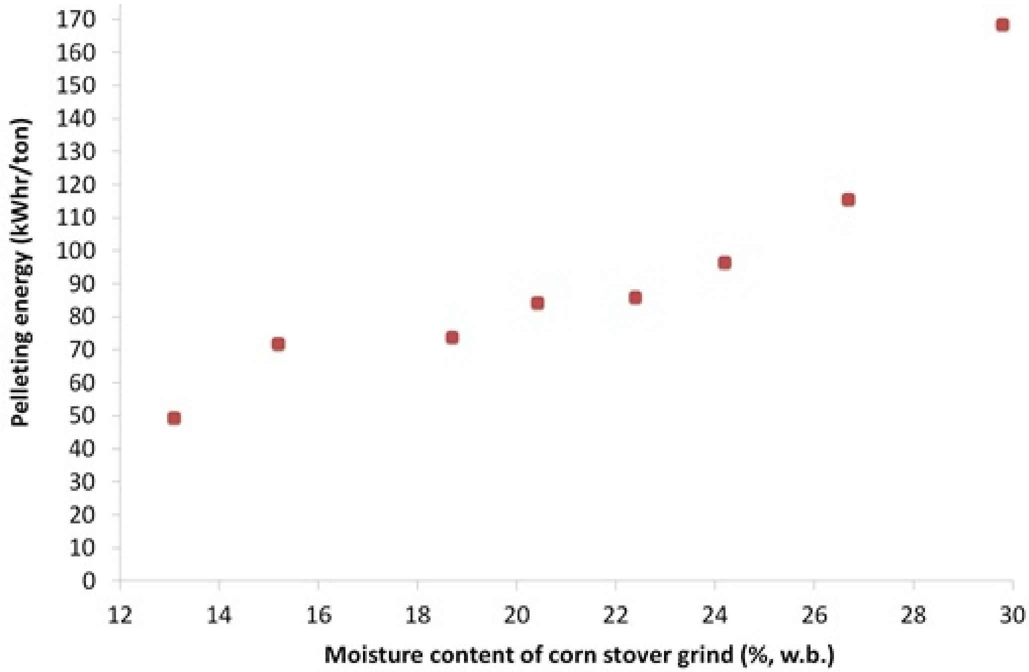


Figure 15 Photograph of corn stover pellets produced at high moisture contents

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