Biomass Energy Pellets

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There is a widespread global shift toward renewable energy sources, where the emphasis is on enhancing the utilization of renewable energy due to the rising costs associated with fossil fuels. In this light, biomass pellets made from woody and non-woody biomass and blends have gained increased attention. Extensive research has been conducted globally to enhance the quality of biomass pellets and to explore the potential to combine woody biomass with other non-woody forms of biomass in biomass pellet production. The heterogeneity of the raw materials used and resulting properties of the biomass pellets have led to the establishment of internationally recognized benchmarks such as the International Organization for Standardization (ISO) 17225 standard to regulate pellet quality.

pellets mixed biomass standards Energy Quality Properties

1. Biomass as a Renewable Energy Source

The adoption of renewable energy sources is rapidly gaining momentum worldwide due to the growing global demand for energy [1][2][3]. There is a significant decrease in global concern about and dependency on fossil fuel energy sources, attributed to various factors such as fluctuations in energy demand, oil price shocks, disruptions in energy supply chains, hampered energy investments, energy price hikes, and energy security challenges [4][5]. Moreover, the urgency to address climate change and pursue low-carbon energy transitions has become a top priority in the energy sector [6]. Consequently, numerous countries have implemented policies to integrate environmentally friendly energy sources into their energy portfolios [7]. Notably, in October 2023, the European Union officially approved an updated Renewable Energy Directive aimed at increasing the share of renewable energy in Europe from 32% to 42.5% by 2030, with the ultimate goal of achieving a 45% share of renewables [8]. While specific targets for individual countries have not been established, each Member State will contribute to this collective objective. Concurrently, renewable resources such as solar, wind, geothermal, biogas, and biomass are gaining substantial recognition as viable options for sustainable and eco-friendly energy [9].

Within this realm of renewable energy, biomass has emerged as a pivotal contender over the last few decades. Its ascendancy is attributed to its renewable nature, environmental cleanliness, robust technical viability, economic feasibility, and widespread availability [10][11][12][13][14]. Moreover, biomass holds a distinct appeal as a renewable reservoir readily transformable into three distinct fuel states—gas, liquid, and solid [15][16][17][18][19][20][21].

Wood possesses the distinct advantage of negligible sulfur content, distinct from coal and liquid fuels, thus mitigating the emission of sulfur dioxide into the atmosphere [22]. Recent scientific inquiries have substantiated biomass as a key energy source with the potential to supplant fossil fuels [23]. Within this context, biomass emerges as a promising remedy to the challenges posed by fossil fuels, including coal and liquid fossil fuels, which are implicated in critical environmental concerns such as climate change, global warming, and their deleterious impact on human well-being [24]. Biomass is important in addressing such predicaments associated with fossil fuels [25].

According to the Statistical Report of Bioenergy Landscape 2020 [26], biomass-derived energy holds the second position in global bioenergy consumption, following nuclear energy, with a substantial market share of 63.11% (123,592 kilotons of oil equivalent (ktoe)), followed by hydro energy at 16.46% (32,242 ktoe) and wind energy at 11.11% (21,768 ktoe) [27][28].

The importance of bioenergy reaches far beyond developed nations and plays a pivotal role in developing nations. Recent studies have shed light on its impressive ability to deliver energy in various forms that cater to people's needs, encompassing liquid and gaseous fuels, heat, and electricity. Therefore, bioenergy plays a significant role in reducing poverty in developing countries while simultaneously tackling the restoration of unproductive and degraded lands [29][30]. This restoration process yields multiple benefits, such as increased biodiversity, enhanced soil fertility, and improved water retention [31][32][33]. Bioenergy remains the primary source of energy in several countries and regions, including Bhutan (86%), Nepal (97%), Asia (16%), East Sahelian Africa (81%), and Africa (39%). In these areas, bioenergy is predominantly utilized for cooking and heating purposes, wherein firewood serves as the main source [31][34]. Particularly, Southeast Asia is rapidly emerging as a vibrant market for the development of biomass as an energy source [35]. Notably, countries such as Malaysia, Thailand, and Indonesia, known for their significant agricultural residues comprising rice, sugarcane, palm oil, coconut, and rubber, are among the foremost producers. Noteworthy crop residues include rice husk, sugarcane bagasse, oil palm residues, and wood residues [36]. The trajectory of bioenergy is witnessing novel trends and growing markets across the globe, with projections indicating that bioenergy will meet 30% of the world's energy demand by 2050 [37][38].

While various forms of biomass, including wood, energy crops, agricultural residues, industrial wastes, and municipal solid waste, are available [39], the utilization of raw biomass is accompanied by certain inefficiencies. Factors such as irregular shapes, low bulk density, and elevated moisture content contribute to challenges in handling, transportation, and storage [40][41][42][43][44][45][46][47]. To tackle these issues, intensive research and implementation of biomass conversion technologies have transpired over the past decade [48][49][50][51][52].

Densification of biomass has emerged as a prominent conversion technology, achievable using distinct processes: pelletization, briquetting, extrusion, and tumbling [53]. This introduction of densification technologies has paved the way for the energy market entry of densified biomass products such as chipped wood, wooden pellets, and biomass briquettes. Moreover, the research underscores the consistent global consumption of firewood and charcoal, along with a twofold increase in the use of wood chips and wood pellets for power generation and residential heating over the past decade. This upward trajectory is projected to persist in years to come [12][13][37][54][55][56].

2. Biomass Pellet Market Dynamics

Biomass pellets, whether with or without additives, are compacted milled biomass typically cylindrical in shape, spanning 5 to 40 mm in standard market length [57]. The surging popularity of wood pellets in heating markets has triggered novel market dynamics and supply chains. Building and industrial heating and cooling in the European

Union constitute 50% of its annual energy consumption [58], with 80% of central heating systems in Germany adopting biomass combustion technologies [59]. Similarly, growing demand for wood pellets as a heat source are observed in both the European Union and Asian countries [60].

In the Asia Pacific region, boasting 76% of the global coal generation capacity and 94% of the new coal plant pipeline [61], wood pellets are positioned as potential coal replacements in power generation. Via processes like torrefaction, hydrothermal carbonization, and steam explosion, wood pellets have gained thermal enhancements to mimic coal properties, advancing their suitability as a fuel [12][62][63][64]. Given the high concentration of coal power plants in the Asia Pacific region, their adoption of biomass pellets has risen, leading to exponential growth in wood pellet imports to South Korea, Japan, and China in recent years. Notably, South Korea's imports surged to 2.4 million tons in 2017, a 20-fold increase from 2012 [65]. Similarly, Japan's 2017 imports exceeded 0.5 million tons, marking a sevenfold rise since 2012 [65][66]. China, with its large population and energy source constraints, has established a substantial potential market. Though ample literature is lacking to substantiate the attainment of the 15-million-kilowatt goal set in its 2016 five-year plan, China stands as the primary producer of bioelectricity, witnessing a 4.5-fold rise in production since 2011 [67].

Approximately half of global pellet consumption serves power generation plants that have transitioned from coal to pellets or engage in co-firing with coal. The other half is predominantly allocated to household heat generation via pellet stoves, boilers, and for industrial steam demand [68][69][70][71][72]. Amidst this landscape, firewood, paraffin, electricity, liquid gas, and natural gas stand as principal competitors to wood pellets in energy generation. However, only firewood surpasses pellets economically; other energy sources falter in terms of toxic emissions, expensive handling, storage, and transportation when compared to biomass pellets [73].

Numerous sustainable indicators and multi-criteria decision analysis research conducted in Germany underscore wood pellets' superior quality and efficiency for private households compared to alternative biomass-to-energy pathways [59][74][75]. The low density of unprocessed biomass such as wood chips (180–220 kg/m^3) poses significant handling and transport challenges, unlike pellets, which offer higher density (around 600 kg/m^3) and energy content per unit volume, thereby reducing costs in transportation, storage, handling, and use [68][76]. Unlike raw biomass, biomass pellets align more closely with liquid fuels in terms of their properties [73][76].

3. Quality Assurance of Biomass Pellets

Biomass pellets must adhere to standardized properties to optimize their utility. Designing boilers, stoves, or pellet burners aligned with these properties ensures effective deployment, catering to diverse scales of demand, from domestic appliances to large-scale power plants [68]. The primary parameters within pellet standards encompass physical attributes such as dimensions, mechanical durability, fine particle content, bulk and unit densities, additives, chemical composition, including sulfur, nitrogen, chlorine, and heavy metals, and energy properties such as moisture and ash content, net calorific value, and energy density [41][77]. These parameters are tied to raw materials, quality management, and manufacturing processes [78].

During 2000–2006, the European Committee for Standardization (CEN) under committee TC 335 established general technical specifications (TS) and testing methods for solid biofuels, culminating in the prEN14961 series by 2014 [79][80]. To align standards globally due to escalating biomass energy production and trade, these specifications transitioned to the International Organization for Standardization (ISO) via the Technical Committee: ISO TC 238 of Solid Biofuels [81]. The ISO released the EN ISO 17225 series in 2014 (ISO 17225-2:2014 [82], ISO 17225-6:2014 [83]), encompassing standards for wood pellets, chips, firewood, and non-woody briquettes, replacing EN 14961 [81][84].

EN ISO 17225-2 [82] for graded wood pellets sets limits for various applications, while EN ISO 17225-6 [83] focuses on non-woody pellets, including blends and mixtures (**Table 1**). Both standards underwent minor updates in 2020 republished in 2021 [85][86]. Graded wood pellets encompass property classes A1, A2, A3, I1, I2, and I3, with distinct quality characteristics for different applications [85]. Non-woody pellets, derived from diverse biomasses, bear higher ash, chlorine, nitrogen, and sulfur contents, warranting tailored combustion systems and corrosion mitigation due to their unique characteristics [84].

Table 1. Specification of graded woody and non-woody pellets.

Parameter	**Unit**	**EN ISO 17225-2**						**EN ISO 17225-6**	
Utility	**-**	**Commercial and Residential Applications**			**Industrial Use**			**Industrial Use**	
		A1	**A2**	**A3**	**I1**	**I2**	**I3**	**A**	**B**
Diameter (D)	Mm	6 ± 1	6 ± 1	6 ± 1	6 ± 1	6 ± 1	6 ± 1	6–25	6–25
Length (L)	Mm	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40	3.15 ≤ L ≤ 40
Moisture content (MC)	%	≤10	≤10	≤10	≤10	≤10	≤10	≤12	≤15
Ash content (A)	%	≤0.7	≤1.2	≤2	≤1	≤1.5	≤3	≤6	≤10
Mechanical durability (Du)	%	≥98	≥97.5	≥96.5	97.5 ≤ Du ≤ 99.0	97.0 ≤ Du ≤ 99.0	96.5 ≤ Du ≤ 99.0	≥97.5	≥96
Fines (F)	%	≤1	≤1	≤1	≤4	≤5	≤6	≤2	≤3
Net calorific value (NCV)	MJ/kg	≥16.5	≥16.5	≥16.5	≥16.5	≥16.5	≥16.5	≥14.5	≥14.5
Bulk density (BD)	kg/m^3	600 ≤ BD ≤ 750	600 ≤ BD ≤ 750	600 ≤ BD ≤ 750	600≤	600≤	600≤	600≤	600≤
N	%	≤0.3	≤0.5	≤1	≤0.3	≤0.3	≤0.6	≤1.5	≤2.0
S	%	≤0.04	≤0.04	≤0.05	≤0.05	≤0.05	≤0.05	≤0.2	≤0.3

Parameter	Unit	EN ISO 17225-2						EN ISO 17225-6	
Utility	-	Commercial and Residential Applications			Industrial Use			Industrial Use	
		A1	A2	A3	I1	I2	I3	A	B
Cl	%	≤0.02	≤0.02	≤0.03	≤0.03	≤0.05	≤0.1	≤0.1	≤0.3
As	mg/kg	≤1	≤1	≤1	≤2	≤2	≤2	≤1	-
Cd	mg/kg	≤0.5	≤0.5	≤0.5	≤1	≤1	≤1	≤0.5	-
Cr	mg/kg	≤10	≤10	≤10	≤15	≤15	≤15	≤50	-
Cu	mg/kg	≤10	≤10	≤10	≤20	≤20	≤20	≤20	-
Pb	mg/kg	≤10	≤10	≤10	≤10	≤10	≤10	≤10	-
Hg	mg/kg	≤0.1	≤0.1	≤0.1	≤0.1	≤0.1	≤0.1	≤0.1	-
Ni	mg/kg	≤10	≤10	≤10	≤10	≤10	≤10	≤10	-

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