A Review of Comprehensive and Ethical Utilization of the Worlds Biomass Resources

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Abstract – In conventional practice, unprocessed biomass resources are transported to biorefineries where they undergo preprocessing to become feedstock before undergoing conversion into various products. The constant supply of biomass to biorefinery cannot be achieved on a just-in-time basis due to the fact that various forms of biomaterials, such as energy crops, logging residue, and agricultural residue, are harvested based on their cycle of development and optimum harvesting timeframe. Biomaterials are typically stored and subsequently transported to biorefineries on an as-needed basis. The current approach has resulted in various challenges concerning logistics, biomass degradation caused by fire and microorganisms, and irregular quality of feedstock as a result of the changing characteristics of the delivered biomass materials. This has been observed through previous encounters. The aforementioned factors have resulted in elevated feedstock expenses, reduced processing capacity, and diminished product output for biorefineries. The present study introduces a novel approach to tackle the challenges associated with conventional methods of biomass feedstock procurement, retention, and preliminary processing, as discussed earlier. This strategy comprises three fundamental elements: firstly, the conservation and preparation of biomass throughout its storage; secondly, the incorporation of all biomass components, even those typically deemed as refuse or impurities; and thirdly, the optimization of the worth of each component. The implementation of this novel methodology involves the establishment of feedstock preprocessing depots in close proximity to the sources of biomass production.

Keywords – Biomass Energy Systems, Biorefineries, Feedstock Preprocessing, Biomass Materials, Biomass Degradation.

I. INTRODUCTION

The utilization of biomass energy systems presents a promising avenue for mitigating the release of greenhouse gases, owing to their substantial capacity to substitute conventional fuels in energy generation. The utilization of biomass has been found to have a positive impact on the environment by reducing emissions and promoting carbon sequestration. This is due to the fact that the cultivation of short-term forests or crops on earlier neglected agricultural land amounts to carbon accumulation in the soil. Bio-energy normally results to an irretrievable mitigation effect by reducing the emission of carbon dioxide at the point of origin. However, it may generate a greater amount of carbon per energy unit in comparison to fossils fuel, unless the biofuel production adheres to sustainable practices. The utilization of thermo-chemical technology for conversion can significantly decrease dependence on fossil fuels through the incorporation of biomass resources. Furthermore, the heightened adoption of fuels derived from biomass will play a crucial role in preserving the environment, creating fresh employment prospects, promoting sustainable growth, and enhancing health conditions in rural regions.

By 2050, the use of bioenergy in the form of electricity and biofuels/biodiesel is projected to account for a significant portion of the renewable energy sources that will make up the world's main energy mix (see **Fig 1**). Using an integrated assessment modeling framework, Ruiz et al. [1] provided an estimation of the highest biomass energy potentials under an environmental protection policy (soil protection and biodiversity) and communal transformation standards from the supply and demand perspective (demand-side policy integrates healthy and sustainable diet; and the supply-side policy integrate trade directness for food and advanced technology). Without any policy in place, we calculated a worldwide advanced bioenergy potential of 245 EJ/year, wherein 192 EJ/year would be generated at a cost of less than $5 USD per gigajoule (GJ). These numbers, with a comprehensive environmental strategy, were 149 and 110 EJ/year, correspondingly. Protecting biodiversity is more effective than protecting soil because it has a wider scope and is more widely implemented.

Even with comprehensive environmental legislation, community transformation standards raise them to approximately 186 and 143 EJ/year, correspondingly. These findings suggest that there may be a trade-off between climate goals (such as maintaining global mean temperature increase well below 2°C based on pre-industrial dimensions) and environmental protection goals (such as maximizing the use of renewable energy sources).

The biomass industry holds considerable significance in various contexts, as it has the potential to impact multiple Sustainable Development Goals (SDGs), such as SDG 5 (gender impartiality), SDG 8 (increased growth within the economy), SDG 15 (land life), SDG 13 (climatic activities), and SDG 7 (environmentally-friendly and affordable energy) in both direct and indirect ways. Over the past two decades, there has been critical research on different biomass to bioenergy conversion routes classified as first, second, and third generation of biomass fuels. Although progress has been made globally, the outcomes have been varied.

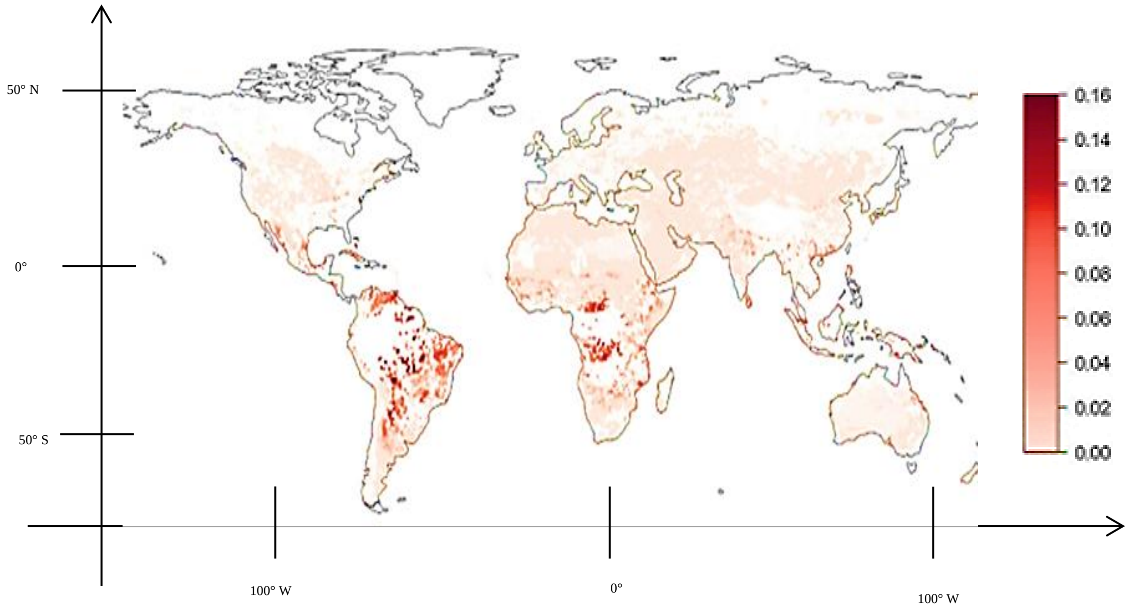

Fig 1. Map of the Potential for Bioenergy in 2050 in a Scenario with demand- and Supply-side Policies (EJ/grid)

According to Röder, Mohr, and Liu [2], the modern bioenergy routes contribute approximately 2% of the globes power generation, which amounts to approximately 637 TWh of electricity on a global scale. The contemporary bioenergy pathway is characterized as biomass transformation into energy through advanced methodologies such as gasification, pyrolysis, and combustion. India, possessing a significant abundance of agricultural biomass, has undertaken various measures to exploit its potential as a source of biomass energy. The primary emphasis of India's biomass initiative centers on the development of biofuels and power derived from agro-forestry and agro-industrial residue sources. India's biomass power potential, including sugarcane bagasse cogeneration, is estimated to be 18 GW. By 2020, India has effectively installed about 10.2 GW of grid bioenergy, which accounts for approximately 11% of the overall installed renewable capacity of electricity, as per Barrera-Santana and Sioshansi [3]. As per the data provided by MNRE in 2021, the states of Maharashtra, Karnataka, Uttar Pradesh, Andhra Pradesh, and Tamil Nadu have been ranked as the top five states in terms of installed biomass electricity capacity, with capacities of 2584 MW, 2117 MW, 1887 MW, 1012 MW, and 484 MW, respectively.

The distribution of biomass is influenced by spatial and temporal factors, with local climatic and geographical conditions playing a significant role in determining its type and availability. The overall biomass resource availability for the generation of bioenergy is influenced by various factors such as physic-chemical features, residue generation ratio, and localized competing applications such as animal feed, heating or cooking fuel, and soil organic fertilizer. According to Aguiar, Milessi, Mulinari, Lopes, da Costa, and Candido [4], having knowledge of these factors could enhance biomass generation during periods of limited feedstock availability and streamline the supply chain, ultimately leading to a reduction in logistical expenses. The biomass databases for crop residue are available at the nationwide level in India and have about a yearly surplus biomass capability of the country to be within the 150 MT to 234 MT range. Nonetheless, databases at a localized countrywide-level are limited to only fewer states.

Several biomass assessment studies conducted at the state level have provided estimates of the potential bioenergy capacity for Haryana (1120 MW), West Bengal (1197 MW), and Punjab (1464 MW to 3172 MW) in India. These studies were conducted by Vijay, Kapoor, Singh, Hiloidhari, and Ghosh [5] in 2012 and 2010. Nevertheless, the aforementioned research endeavors have solely focused on the excess crop residue biomass and have not considered the significant potentials of livestock manure as a bioenergy source. According to Hadiyanto, Christwardana, and da Costa [6] the primary biomass sources for energy generation are energy crops cultivated for that purpose and discarded materials. Energy crops, such as coppice (short rotation woody crops), and Miscanthus, are primarily grown for energy generation and are focussed on food versus fuel discourse, which pertains to the allocation of land for fuel production as opposed to food cultivation. According to Tripathi, Hills, Singh, and Atkinson [7], utilizing agricultural residues, including but not limited to canola, barley, wheat straw, and oat for energy production presents a solution to the food versus fuel predicament while simultaneously enhancing the worth of current crops. The residues in question constitute a plentiful, cost-effective, and easily accessible reservoir of sustainable lignocellulosic biomass.

The examination of biomass power-related emissions by Kaliyan, Morey, and Tiffany [8] has been lacking in order to assess the potential reduction of greenhouse gas emissions at the state level through the utilization of surplus biomass. The majority of previous state-level studies have not included an evaluation to understand the possible variation in biomass resource accessibility, the degree of biomass-generated energy potentials, the resultant emissions and emissions savings in comparison to fossil power. Given the localized and decentralized nature of biomass applications, the availability of a region-specific database would aid decision-makers in prioritizing investments and devising sustainable long-term plans. The examination of state-level systems has the potential to facilitate the production of a greenhouse gas (GHG) emission reduction inventory for bioenergy at a regional level. The utilization of clean bioenergy has the potential to stimulate entrepreneurial endeavors and garner foreign investment through various channels such as the Clean Development Mechanism (CDM), and Green Climate Fund (GCF), and other similar mechanisms.

The main focus of this paper is the sustainable utilization of biomass resources, with a particular emphasis on herbaceous energy crops and corn stover. The present study introduces a novel approach to tackle the issues associated with conventional methods of biomass feedstock supply, storage, and preprocessing as discussed earlier. This strategy comprises three essential elements: (1) the conservation and preparation of biomass throughout its storage, (2) the incorporation of all biomass components, even those typically deemed as refuse or impurities, and (3) the optimization of the worth of each constituent. The remaining part of the article is organized as follows: Section II presents a background overview of the article. Section III focuses on biomass logistics and its supply. Section IV presents a discussion of biomass pre-processing and fractionation. Section V discusses product application and present concerns of biomass utilization. Lastly, Section VI presents concluding remarks to the paper.

II. BACKGROUND ANALYSIS

The primary cost driver in the production of cellulosic biofuels is the expense associated with feedstock acquisition. According to a study conducted in [9], the National Renewable Energy Laboratory (NREL) has estimated that in order to achieve the Department of Energy's fuels selling cost objective of approximately $2.5 per GGE by the year 2030, the biomass feedstocks cost distributed to reactor throats for bioenergy-to-hydrocarbons fuels biochemicals conversion facilities should not surpass $71 per drier short ton. Drawing from the experience at Pioneer Biorefineries, it can be inferred that achieving the aforementioned target price would pose a significant challenge with the current technological capabilities. Furthermore, it is important to note that the feasibility of this target price is contingent upon the availability of low-cost biomass in specific locations. Apart from the acquisition of economical feedstock, a significant challenge associated with the traditional methodology pertains to the intricate preprocessing of unprocessed biomass resources, particularly bundled agricultural residues, which frequently results in reduced equipment uptime. As per the report by the US Department of Energy in 2016, the primary obstacles recognized by the industry are related to the flowability of biomass feedstock, the inconsistency in feedstock characteristics, insufficiency of tool-performance dataset, and the absence of standardized feedstock specification. Furthermore, the amalgamation of feedstock preprocesses and biofuel conversion within a singular facility results in reduced plant efficiency, as complications arising in the preprocessing domain frequently lead to the cessation of downstream conversion-unit operations.

Gonzales, Searcy, and Ekşioğlu [10] proposed a strategy to decrease the expenses associated with the transportation of biomass feedstock. This approach involves the combination of carbohydrate biomass, e.g., switchgrass, or 2-pass corn stove, with lower-cost biomass, e.g., grass clipping. The recommended cost of this method was $79.1/dry short ton by 2022. The process of pelleting blended biomass materials is employed to enhance their handling properties at the biorefinery, as well as to enable high-density storage and transportation. The blending methodology is constrained to regions where biomass materials with high carbohydrate content and low cost are obtainable. The variability in concentrations of carbohydrates and lignin in biomass feedstock poses a challenge for biorefineries seeking to convert these components into biofuels and high-value coproducts. This complexity necessitates a significant investment in capital that could be a vital obstacle to commercialization, particularly for emerging innovations. According to Cho, Chung, Kim, Suh, Koh, and Choe [11], the projected capital costs for a cellulosic ethanol plant producing 50 million gallons annually is approximately $4.30 (in 1999 dollars) per annual gallon, which is notably higher than the estimated $1.2/year gallons for drier-grind corn-ethanol crop.

The Idaho National Laboratory is currently engaged in an investigation of a novel method for the preservation of biomass and the conversion of raw biomass into various feedstocks that are conversion-ready. The aim of this approach is to cater to a diverse range of markets, such as biofuels, animal feed, agriculture, and bioproducts. The preprocessed biomass material holds a greater potential value as compared to single-use. The establishment of feedstock depots catering to a greater customer base can mitigate the financial threat associated with such ventures. The feedstocks that are ready for conversion can be customized to meet the specific requirements of the end users. The aforementioned methodology integrates the pre-treatment of biomass in storage to reduce the microbial breakdown of carbohydrates, alongside fractionation techniques to generate products of significant economic worth. The subsequent segments offer an analysis of fundamental constituents of a sophisticated feedstock preprocessing facility that would yield numerous advantages, including streamlined logistics for biomass supply, preconditioning of stored materials, and retrieval and separation of products.

III. BIOMASS LOGISTICS AND SUPPLY

According to Hakeem et al. [12], corn stover has been identified as an agricultural residue with the highest abundance and suitability for conversion into biofuels and chemicals. Within the realm of agriculture, the prevalent techniques for the storage of agricultural residue encompass two primary methods: (1) the utilization of round or square bales and (2) the implementation of bunkers or ensiled piles. Given an estimated mean dry mass of about 500 kg/square bale, a facility with a daily output of 2,000 metric tons will necessitate the utilization of 4,000 bales per day. It is important to note that this calculation does not account for any potential dry matter losses that may occur during the preprocessing and storage stages. The standard inventory timeframe for biorefinery is 5 days. According to Wei et al. [13], in order to maintain a 5-day inventory for a facility with a capacity of 2,000 tons/day, the area of storage should be no less than 5.9 hectares (14.5 acres). This calculation is based on the assumption that each stack of 2,000 bales is 7 bales higher and spaced about 60 meters apart to mitigate the potential spread of fire between stacks.

The study conducted by Chandler and Jewell [14] involved the collection of data pertaining to the duration of the corn grain harvesting period and the progress of the harvest across various states. The data presented on a weekly basis pertains to the aggregate proportion of corn units or quantities that have been harvested during the period spanning from week 36 to week 45. This information is displayed in **Fig 2**. In week 36, there is a higher percentage of harvest in warmer regions compared to a lower percentage of harvest in colder regions. The data presented in **Fig 2** indicates that while the last harvested grain percentage is higher at the end of the harvesting period (mostly in the 45th week), it is notable that the last percentage of the harvested crop in cold regions falls below 100%. The precise commencement week of the harvest season for each state is not documented. However, the ultimate week of the harvest season typically extends until week 47.

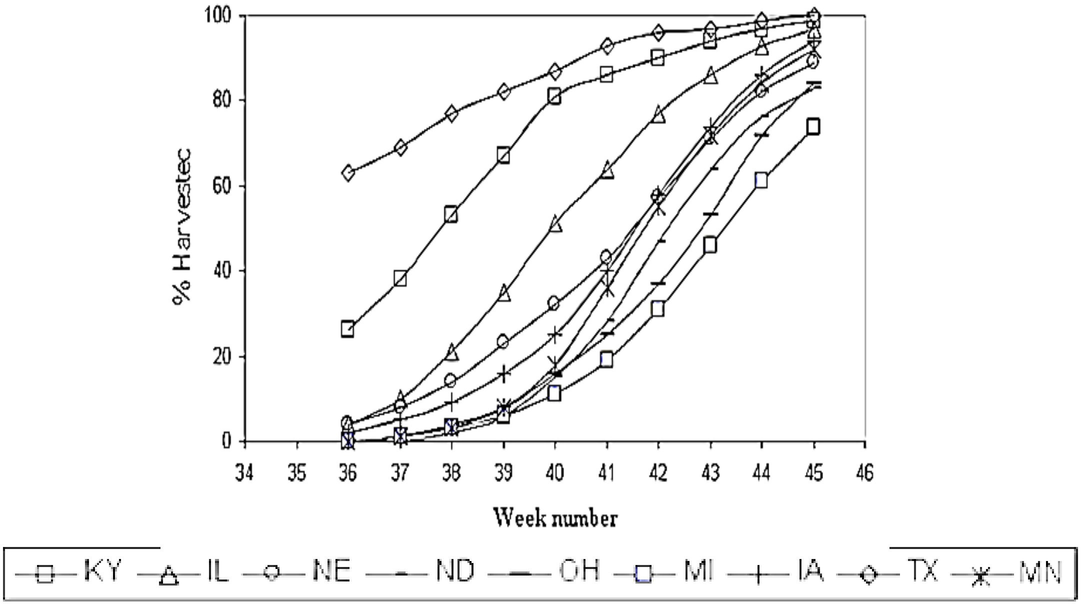

Fig 2. Progress in the Cumulative Corn Harvest from Different Corn-Growing States [15]

The average duration of the corn stover harvesting period is 4 months, and to store an 8-month bale distribution in remote storage areas, a minimum area of 256 hectares (633 acres) is required. The expenses associated with the conveyance and conveyance of bales from the fields to satellite storage areas and consequently to biorefineries constitute a noteworthy component of the feedstock cost. The biomass bale storage (e.g., corn stover) presents several challenges that result in significant dry matter loss, feedstock property variability, and elevated expenses.

If a stack of 2,000 bales, which is 7 bales high, remains uncovered, it is necessary for up to 60% of bales to realize about one side open to either the external air or the ground. When the uppermost layer of the pile is obscured, approximately 45% of the bales become visible. According to Smith, Bonner, Kenney, and Wend [16], the exposure of bales to moisture movement results in increased degradation and inconsistent properties. According to [17], the operability of feedstock-preprocessing equipment is significantly impacted by two major properties, namely moisture and ash. According to Polin, Carr, Whitmer, Smith, and Brown [18], the presence of multiple corn stover bale layers and higher moisture levels can lead to a decrease in the efficiency of bale grinders, as well as the occurrence of surge flows and inconsistent particle size. According to Nguyen, Smith, Wahlen, and Wendt [19], the utilization of multipass baling logistics results in an elevated level of extrinsic ash content as a consequence of soil contamination.

An additional concern pertaining to bale logistics pertains to the significant polypropylene twine quantity used for polyethylene bale net wrap and square bales used for the round bales, which necessitates appropriate disposal measures. According to estimates, a biorefinery with a daily capacity of 2,000 metric tons that employs square bales as feedstock produces approximately 8.4 million units of twine measuring 6.7 meters in length per year of operation. The utilization or repurposing of such refuse may pose challenges for numerous rural areas. The majority of sizable square balers tend to produce multiple sections of twine, commonly referred to as tailings, which measure approximately 2-4 centimeters in length, on the resultant bales. The detection and removal of these contaminants pose significant challenges. The efficacy of contemporary mechanical technology in eliminating bale twine and net wrap is less than 100%. According to [20], the presence of Twine and net-wrap contaminants may result in the obstruction of piping and equipment.

The mechanical and physical characteristics and chemical compositions of corn stover that integrate cob, hust, stalk, leaf, and residuals of softwood logging that include twigs, white wood, needles, and bark, are subject to variability due to their heterogeneous nature. The presence of such variabilities gives rise to issues pertaining to material handling and operations, thereby leading to reduced throughput and product yields in the initial biorefineries. One approach to mitigating concerns related to material handling and conversion yield involves the fractionation of biomass into its primary constituents, followed by the conversion of these constituents into feedstock that is readily convertible. The practice of storing feedstock in an anaerobic environment with high moisture content (40-65% wet weight basis) presents several benefits when compared to bale storage.

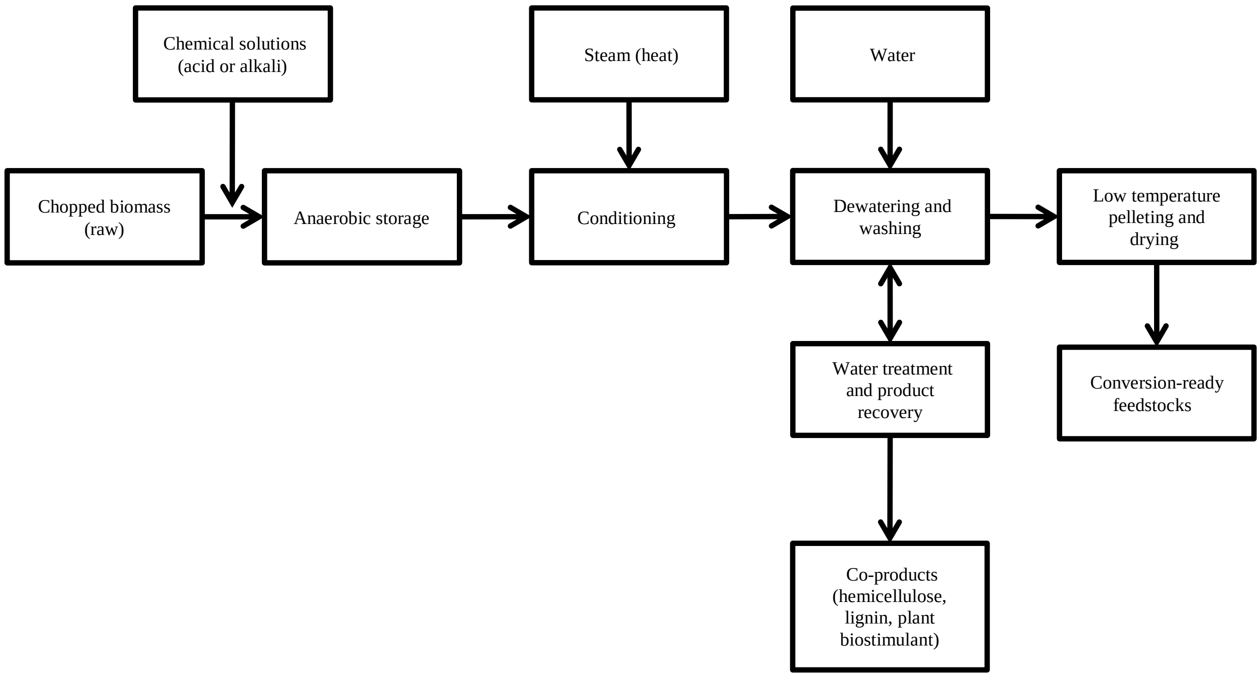

Fig 3. Storing Biomass Anaerobically at High Moisture and Fractionating

These benefits include reduced dry matter loss, as reported by Lazarus and Lawa [21], decreased risk of fire, and lower handling costs. Additionally, it affords the prospect of conducting leaching, microbial, or chemical preconditioning procedures while in storage. In contrast to bales storage, the pile storage necessitates a notably reduced storage facility. For instance, a 2,000 metric ton/day facility's 5-day inventory pile only necessitates approximately 1.58 acre (0.64 hectare) when a proposed mean-compact bulk density of about 15 lb/ft^3 (240 kg /m^3) dry bases is applied to accomplish low drier matter loss, as per Zhang, Brown, Hu, and Brown [22]. The storage pile may be situated in close proximity to the biorefinery, facilitating the transportation of the feedstock from the storage location to the processing facility. Consequently, there is a reduction in handling expenses.

According to Kenney, Hess, Stevens, Smith, Bonner, and Muth [23], the utilization of biomass-chopping logistics is efficient for an anaerobic storage of high-moisture herbaceous energy crops, in contrast to baling logistics. According to [24], it is possible to achieve a reduced bulk density of 1^3 lb/ft^3 (208 kg/m^3) or higher for dry chopped corn stover by utilizing a diameter of 0.3 m auger. In terms of comparison, it has been observed that the bulk corn stover density of square bales is about 11 lb/ft^3 (177 kg/m^3) while the round bales exhibit a density of around 8.8 lb/ft^3 (141 kg/m^3) on a drier basis. According Narendranathan and Lee [25], the utilization of mobile screw compactors is feasible for the compression of biomass that has been chopped into transporting instruments within the facility. The compressed organic matter may subsequently be transported to depots for preliminary processing into densified feedstock that is ready for conversion. **Fig 3** depicts a plausible arrangement for the logistics of chopped biomass.

The process of harvesting corn stover involves the use of a single-pass harvester that expels chopped stover into forage wagons that are mobile and situated within the field. The transportation process involves pulling the wagons to the field periphery, where chopped biomass is directly conveyed in closer pre-processing depot or compacted within transporters. According to [26], it was found that forage wagons have the ability to precompact chopped biomass to a density of 112 kg/m^3 to 139 kg/m^3 on a drier basis. The possibility exists for a reduction in the net cost of transportation and dealing with corn stovers that have been chopped when compared to baled corn stover. This is due to the shorter overall distance required for travel to the localized depot and the removal of bale storage and its processes of handling. **Table 1** outlines the primary benefits of utilizing chopped bio-energy logistics in contrast to the baling logistics.

Table 1. Quantitative Evaluation of Different Aspects of Logistical Baling and Strategies of Chopping for Herbaceous Biomass

Waste streams	Bale twines and net wrap may have harmful effects on the environment and wildlife if not disposed of properly.	There will be zero squandering of bale twines and net wrap. Reduce your carbon footprint and negative effects on the environment.
Weather impacts	Field drying and baling may be delayed by wet and cold weather. As a consequence, the availability of biomass is restricted to regions with stable climate conditions.	The harvest and gathering process is less affected by weather than the baling process.
The effects on the operations of feedstock depots and biorefineries	Due to the wide range of biomass characteristics, operational dependability and product output are low. Biorefineries have higher starting and running expenses.	Enhanced operational dependability and decreased capital and operating expenditures.
Making it easier to produce a wide variety of goods, such as feedstocks ready for conversion?	No, the cost would be too high.	Yes, biomass storage activity of high moisture may easily include both biological and chemical processes.
Cost of handling and storage	Bale stack consume more room and should be kept at a safe distance from one another to prevent fires from spreading. Bales have 9 times as much storage space as heaps, and there are also several satellite bale storage facilities.	The biomass may be stored in heaps close to the feedstock depots and then transported from there to the preprocessing area. The transport costs are reduced by situating the modular depots in close proximity to the biomass sources.
Fire risk	Danger of fire from many sources; not just candles and cigarettes.	Extremely low fire danger due to high humidity (>45%) and lack of oxygen.
Biomass features	Moisture content, ash content, fiber integrity, size of particles, and chemical makeup all range widely.	Better uniformity of characteristics than baled biomass
Loss of dry materials due to weeks or months of outdoor storage	10-20%, based on the bales' relative humidity and the outside temperature	5%-6% in anaerobic conditions
Harvesting and collecting agricultural waste leftovers	Common	Rare in most contexts, although often used to make silage

The billion-ton report has identified logging residues as a potentially cost-effective source of woody biomass. The logging residues of softwood primarily consist of branches and treetops. Through appropriate storage and preprocessing techniques, it is possible to transform logging residues into a viable feedstock that can be utilized for thermochemical conversion into biofuels. In order to reduce soil contamination and streamline in-field preprocessing, it is recommended that logging residues be warehoused in piles rather than dispersed on the surface. According to Spanoghe [27], it is recommended to season the residues for a period of at least one year or more to reduce the content of moisture to a wet basis (about 25%) and to aid in the process of defoliation. Achieving a moisture content of less than 25% through pile drying may present challenges in areas with elevated annual precipitation.

Typically, within the Southeastern region of the United States, the reduction of moisture content in logging residues to approximately 30% occurs over a period of one year. Conversely, the duration of this process is prolonged in the Pacific Northwest region of the United States. The act of drying logging residues may lead to a decrease in the effectiveness of bark removal, as the strength of adhesion between the wood and bark is notably greater when the moisture content falls below approximately 40%. The process of managing logging residues involves several steps, including sorting, screening, and chipping the materials in the field. Once this is complete, the residues are compacted using transporters and subsequently transported to preprocessing depots for further handling.

IV. BIOMASS FRACTIONATION AND PREPROCESSING

The primary objective of biomass pre-processing is to generate uniform feedstocks, which conforms to the requisite conversion criteria. The diverse composition and characteristics of softwood logging residue and corn stover have presented significant challenges in conventional preprocessing methods such as screening, air classification, and milling. The mechanical forces necessary to fracture different anatomical components of corn stover, such as leaf, cob, husk, pith and rind, exhibit variations based on the specific tissue type. The pulverization of fragile elements such as leaf and pith can result in a wider particle-size supply with a vital fine proportion when applying adequate levels of effect and the shear force for fracturing resilient elements such as rind, husk, and cob. The potentials of uneven flow of mass, heat and mass transfer in a continual high-solid pre-treatment reactor can be attributed to a wide particle-size distribution. Zhuo et al. [28] have shown that the corn stover rind exhibits greater recalcitrance compared to the pith and leaf fractions. As a result, it is likely that mild pretreatment approach, such as dilute sodium hydroxide and hot water pre-treatment, may lead to a reduced enzymatic-hydrolysis sugar yield when applied to corn stover.

According to Zhang, Zheng, and Qian [29], a viable approach to attaining a total sugar yield of over 90% in corn stover after enzymatic hydrolysis and pre-treatment involves the utilization of higher temperatures, short-term residence duration dilute sulfuric acid explosion pretreatment of steam. The aforementioned pre-treatment technique has demonstrated efficacy in breaking down the resistant fibers of the rind. However, it does not result in significant degradation of more susceptible constituents such as the pith, leaf, and husk. The aforementioned technique bears resemblance to the amplified milling forces, whereby heightened processing intensity is employed to surmount the heterogeneity of biomass. Lignin, products of carbohydrate breakdown, and organic acids are released during the dilute acid pretreatment process. These compounds have inhibitory effects on both fermenting and enzyme organisms.

A viable approach involves the fractionation of corn stover into its primary anatomical constituents, followed by individual processing of each component. The economic feasibility of this approach is contingent upon the development of high-value applications for one or more of its constituent elements. Ashrafi Birgani, Talaeipour, Hemmasi, Bazyar, and Larijani [30] have reported that the production of bleached soda pulp from the corn-and-stover stalks is feasible. However, the availability of pith in the stalks has been found to result in low yield and poor drainage. It is anticipated that the utilization of depithed corn stalks will enhance drainage and facilitate the production of corn-stover pulp. The present methodology involves the fractionation of corn stover at the time of harvesting, prior to the amalgamation and compaction of all the constituents, as in the case of baling. The intermingling of these anatomical constituents poses a significant challenge in their separation.

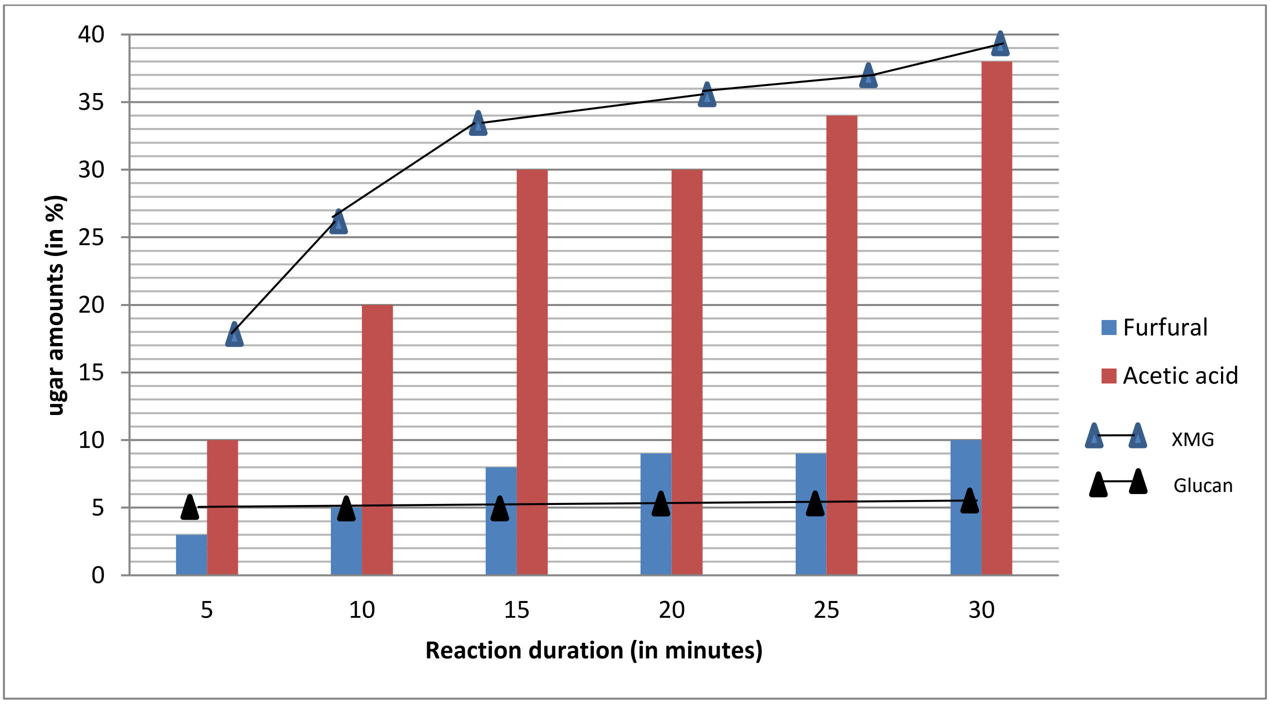

Fig 4. The effect of reaction time on glucan, and XMG yield, as well as the concentrations of acetic acid and furfural; the experiment was conducted at a temperature of 190 ◦C with a solid/liquid ratio of 1:8 and 0.1 wt.% of H_2SO_4.

According to Singh, Nara, Rani, Pathak, Sangha, and Kaur [31], it is feasible to partition corn plants into two distinct fractions during the harvest process: one consisting of stalks and leaves, and the other consisting of husks and cobs. Through the implementation of screening and air classification techniques, it is possible to effectively segregate the leaves from the stalks, as well as to separate the husk from the cobs. The segregation process has the potential to be executed on-site prior to the consolidation of the diverse components into conveyance vessels. According to Zhang, Cheng, Ma, Zhou, and Y. Xu [32], it is possible to de-pith the stalks at pre-processing depots based on the application technology that is the same as that utilized for industrial hemp and sugarcane bagasse de-pithing.

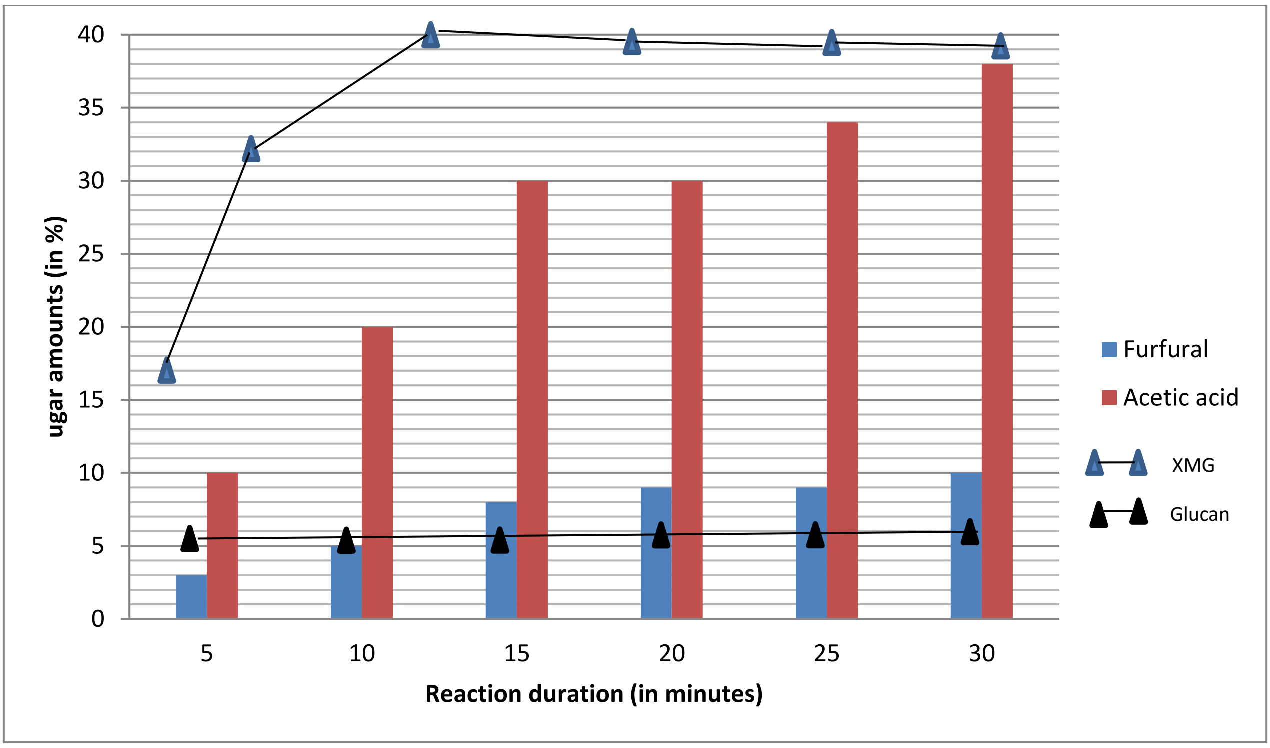

Fig 5. The effect of reaction time on the yield of glucan and XMG, as well as the concentrations of acetic acid and furfural; the experiment was conducted at a solid/liquid ratio of 1:8 and an H2SO4 concentration of 0.25 wt.% at a temperature of 190 ◦C.

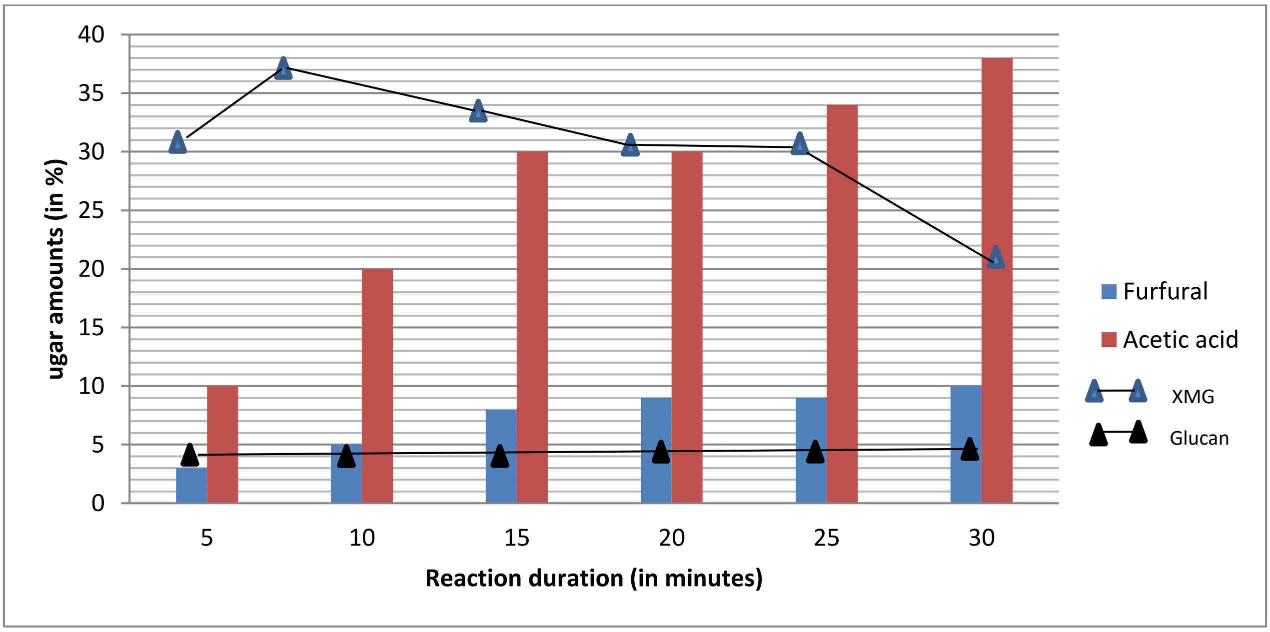

Fig 6. The effect of reaction time on the yield of glucan and XMG, as well as the concentrations of acetic acid and furfural; the reaction was conducted at a solid/liquid ratio of 1:8 and a temperature of 190 ◦C, with the addition of 0.5 wt.% of H2SO4.

Chemical fractionation can be employed as an alternative or supplementary method to anatomical fractionation for biomass separation. As depicted in **Fig 4**, the employment of 0.1 wt.% sulfuric acid for fractionation resulted in an escalation of XMG yield with the progression of reaction time, culminating at 57.5% after 15 minutes. However, a marginal decline in yield was observed beyond the 15-minute mark, which could be attributed to the excessive decomposition of xylose. The study found that the glucose release remained consistent at approximately 5% throughout the reaction progression. However, there was a proportional increase in the concentrations of the by-products furfural and acetic acid as the reaction progressed. Upon a reaction time of 25 minutes, a concentration of 1 gram per liter or higher was verified in the instance of furfural. The alteration in the fractionation yield of XMG over time, while keeping other conditions constant as previously stated, is illustrated in **Fig 5** when fractionation was executed using 0.25 wt.% sulfuric acid. The XMG yield exhibited a comparatively elevated value of 65.8% after a reaction time of 10 minutes, which is shorter than the duration required for fractionation with 0.1 wt.% sulfuric acid. The maximum XMG yield of 67.9% was achieved after a reaction time of 15 minutes.

During the course of the reaction, it was observed that the yield of XMG decreased at a comparatively faster rate than that observed in the presence of 0.1 wt.% sulfuric acid. The findings indicate that the release of glucose was marginally greater in comparison to the scenario where 0.1wt.% sulfuric acid was employed (6.5~7.6%). Moreover, as the temperature increased, a greater number of acetyl groups were liberated from hemicellulose and were observed in the fractionated hydrolysate. The concentration of acetic acid demonstrated an increase at the 10-minute mark and surpassed 4 g/L or greater subsequent to 20 minutes of fractionation. The concentration of furfural, a derivative of decomposition, exhibited a gradual rise over the course of fractionation. It surpassed the threshold of 1.0 g/L after 10 minutes and reached 1.77 g/L at the 30-minute mark.

The utilization of 0.5 wt.% sulfuric acid (as depicted in **Fig 6**) resulted in a notable deviation in the fractionation process compared to the utilization of 0.1 and 0.25 wt.% sulfuric acid. Following a 5-minute fractionation process, a significant yield of XMG amounting to 74.3% was achieved, with the maximum yield of 82.1% being attained after 10 minutes. Subsequently, there was a notable decline in the yield as the reaction progressed. Following a 30-minute fractionation process, a yield of 24.6% XMG was achieved, which equates to approximately 30% of the maximum yield. As a result of the XMG over-decomposition reaction, the concentration of furfural in the hydrolysate exhibited a consistent increase, reaching a concentration of 2.93 g/L following a 30-minute fractionation period. This observation suggests a significant loss of xylose.

The extraction of lignin can be achieved through alkali pre-impregnation process when storing, as suggested by Zhou, Xing, Zhang, and Pu [33], which can be followed by washing and conditioning. The conditioning process involves subjecting the material to elevated temperatures exceeding 50°C or/and administering supplementary chemical treatment e.g., peroxide to enhance the process of delignification, as suggested by Cara, Ruiz, Ballesteros, Negro, and Castro [34]. The fiber that has undergone partial delignification is subjected to a washing process to retrieve solubilized products. Subsequently, it is physically dewatered, destructured, air-dried, and finally pelletized to yield a feedstock that is complete for conversion. The co-product known as the liquid fraction is comprised of lignin, organic acids, soluble carbohydrates, minerals, and different additional extractives.

V. PRODUCT APPLICATION AND CURRENT ISSUES OF BIOMASS UTILIZATION

Product Application

Enzymatic hydrolysis technology-based biorefineries that are pioneering in nature typically employ lignin, which is left over after the fermentation process, as a source of fuel in a biomass boiler. The method of utilizing lignin is deemed to be of limited worth as a result of lower value of calorific of the high-moisture lignin cake, which is approximately 50% on a wet weight basis. The presence of extractives, organic acids, phenolics, and inorganics necessitates the need for remediation or waste treatment prior to disposal, leading to heightened operational intricacy and expenses. Preprocessing depots for feedstock that employ fractionation techniques have the potential to generate a variety of distinct products that cater to a broad range of customers, such as producers of biofuels, biochemicals, biomass power, agriculture, horticulture, and animal feed.

The majority of the collection comprises embedded pre-processing approaches. The embedding of active biomass-preprocessing control such as leaching, sixing, sorting, fractionating, drying, and densifying, into the supply systems of biomass has the potential to mitigate complications in systems of downstream conversion. The collection presents a comprehensive analysis of six distinct preprocessing techniques that are utilized for the generation of feedstocks that are suitable for conversion purposes. The present matter underscores a study that utilizes biomass preprocessing techniques such as sorting, fractionation, blending, leaching, and sizing activities to improve the quality of materials for subsequent conversion processes. The optimization of conversion through the separation of biomass components is addressed by Zhang, Wang, Sun, Wang, and Liu [35]. Yang, Chu, Hao, and Zhou [36] investigate the utilization of leaching as a preliminary stage to enhance the quality of biomass and generate co-products. Similarly, Smith and Klosek [37] document the advantages of employing air categorization and separation techniques for biomaterials to facilitate subsequent conversion processes.

The second technique discussed pertains to the amalgamation of feedstocks. Ahn, Choi, and Kim [38] have proposed the practice of blending diverse biomass varieties as a means of addressing the issues of rheological and compositional inconsistency that are commonly observed in singular biomass sources. The third technique that has been discussed pertains to the preprocessing and pretreatment of biomass materials in order to facilitate their conversion. Grejtak et al. [39] discuss the various mechanical techniques employed in the preprocessing of biomass, while Campos, Fronza, Rodrigues, Souza Chiari, and Braga [40] present their findings on the chemical approaches employed in the preparation of biomaterials for conversion. Muazu, Borrion, and Stegemann [41] present a discussion of the fourth approach of biomass densification, focusing on pelletizing and preprocessing methods that aim to minimize losses in the supply system. The impact of storage on downstream conversion and biomass quality has been examined by Gudavalli, Bose, Donohoe, and Sievers [42]. These studies evaluate the efficacy of wet storage in preserving and enhancing biomaterials for conversion. The study investigates rapid and high-throughput approaches for evaluating biomass characteristics and their performance, which serve as instruments for enhancing comprehension and progress of conversion-ready feedstocks. This is also examined by Hess, Ray, and Rials [43].

The utilization of flowable pellet form feedstocks that are readily convertible will enhance the dependability of operations and decrease the capital and operational expenses of biorefineries. When utilizing chopped biomass logistics, feedstock depots do not produce any waste stream of polyethylene net wrap and bale polypropylene twine. The liquid stream may undergo additional fractionation processes to retrieve a lignin powder product that integrates acid filtration and precipitation. In addition, a liquid product is obtained that contains various soluble components such as organic acids, carbohydrates, phenolics, inorganics, and extractives. The fluid substance has the potential to function as a biostimulant, facilitating the growth of plants. Alkali lignin has been identified as a potential supplement for phenol in various applications involving lignin-produced phenolic-resin, such as the production of composite wood products, lignin-based polymers, and as an antioxidant and antimicrobial agent. Additionally, alkali lignin can be converted into fuels and chemicals. According to Hewavitharana, Perera, Navaratne, and Wickramasinghe [44], it is possible to extract fatty acids and resin from the low-value logging residues fractions, such as small branches, bark, and needles.

Current concerns of biomass utilization

The primary issue associated with agricultural straws pertains to its comparatively reduced density in both its unprocessed and baled configurations. According to Chevanan et al. [45], standard and loose baled straw exhibit bulk densities of approximately 100 kg/m^3 and 40 kg/m^3, correspondingly. In contrast, unprocessed residue of wood has a bulk density of about 250 kg/m^3. The comparatively lower density of straw results in higher transportation costs as compared to wood and coal, owing to the reduced amount of straw, which could be distributed per unit volume. Furthermore, baled straw necessitates a greater storage capacity in comparison to wood chips. The process of densification through pelletization has been found to enhance the bulk density of biomass, as evidenced by studies conducted by Zamora-Cristales, Sessions, Smith, and Marrs [46]. This increase in bulk density leads to a corresponding increment in the overall calorific content for every unit volume, as reported by Llewellyn Smith and Hattori [47]. Additionally, the densification process confers benefits in terms of easier and more cost-effective storage, transport, and handling of the material, as noted by Zhao, Zhang, Xu, and Zhang [48].

The evaluation of fuel pellet quality is commonly conducted through the analysis of its density and durability. The literature suggests that the storage and transport capacity of pellets can be enhanced by increasing their bulk density. According to Gilvari, van Battum, van Dijk, de Jong, and Schott [49], it is advisable to prevent fluctuations in bulk density as the feeding of boilers and gasifiers is typically dependent on volume. According to Nielsen, Mandø, and Rosenørn [50] design specifications, wood pellet producers should aim for a bulk density of 650 kg/m^3. The limited durability of pellets can lead to various issues such as interference within the pellet feeding systems, elevated levels of dust emissions, and heightened potential for fire and explosions during the handling and storage of pellets.

The process of increasing the density of straw and identifying the most effective parameters is a complex and specialized skill. The comprehensive procedure entails the acquisition straws in bales from agricultural facilities, decrease in sizes through grinding and chopping, application of pre-treatment approaches encompassing physic-chemical, chemical and biological methods, evaluation of the frictional and physical features of straw grinds, analysis of the lignocellulosic properties of straw, densification of grinds into pellets at both laboratory and pilot scales to assess the impact of different independent variables on the parameters of quality such as durability and density, and energy balance and analysis.

VI. CONCLUSION

The present agricultural technique of performing multiple rounds of harvesting, gathering, and bundling of herbaceous biomass is inadequate in furnishing feedstock that satisfies the necessary biorefinery specifications, unless costly and intricate preprocessing methods are employed to generate uniform quality feedstock from raw biomaterials, which have vital variability in terms of features. The application of 1-pass chopped bio-energy logistics models, integrated with in-field compactions and biologically-handled anaerobic storage could efficiently limit soil contamination and reduce contaminations such as net wrap and bale twine. Additionally, this approach presents promising opportunities for the fractionation of biomass into useful products and the reduction of waste streams. In addition, it is possible to configure a preprocessing facility in a flexible manner to generate feedstocks that are suitable for conversion technologies with specific quality requirements. The concept entails the establishment of feedstock depots, which could potentially furnish the conversion-ready feedstock to various conversion approaches, thereby generating a diverse array of coproducts. This approach would enable the depots to function as self-sustaining commercial entities, rather than being reliant on a solitary biorefinery. The aforementioned methodology possesses the capability to reduce technical and economic hindrances in the development of a biobased economy. The initial users of multi-product feedstock depot incorporate biomass feedstocks distributers and integrators, biomass-pellet producers, wood-mulch producers, and feed aggregators. The company is currently engaged in biomass preprocessing and caters to established industries, including but not limited to biomass power plants, pulp and paper, and wood products, feed lots, and horticultural sectors. Stimulating the producers of biomass feedstocks to diversity their portfolio of products by integrating high-end products such as lignin, conversion-ready extractives and feedstocks could serve as a motivating factor.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate

The research has consent for Ethical Approval and Consent to participate.

Competing Interests

There are no competing interests.

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