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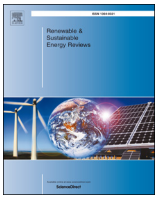

Techno-economic and environmental assessments of storing woodchips and pellets for bioenergy applications

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ABSTRACT

Storage is the critical operation within the biomass supply chain to reduce feedstock supply risks and to manage smooth year-around operations of a biorefinery or a bioenergy plant. This paper analyzed the economic and environmental impacts of four different biomass storage systems for woodchips (Outdoor-open, Outdoor-tarped, Indoor, and Silo) and two systems for pellets (Indoor and Silo). Storage cost includes the costs for handling (including ventilation in case of silo storage), infrastructure investment, and dry matter loss (DML) for each system. The estimation of total greenhouse gas (GHG) emissions includes the fugitive emissions from storage piles and emissions due to electricity and fuel consumption for each system. Among four storage systems, the outdoor-tarped (\$15.0 ODMT^{-1}, ODMT: Oven Dry Metric Ton) and silo (\$5.8 ODMT^{-1}) storage were the least-cost options for woodchips and pellets respectively. However, silo-storage could be the most promising option for storing woodchips (\$5.8 ODMT^{-1}) and pellets (\$2.3 ODMT^{-1}), if it is used for short-term (two months) and frequently (at least six times) in a year. The total GHG emissions for six-month storage were 2.8–11.8 kgCO$_2$e ODMT^{-1} for woodchips and 8.6–42.0 kgCO$_2$e ODMT^{-1} for pellets. During Outdoor-open storage, the lower heating value of woodchips could drop to 37% due to increased dry-matter loss (DML) and moisture content. The initial moisture content, bulk density, DML, and resource required during handling were the most sensitive parameters influenced the storage performances of both woodchips and pellets. This study has demonstrated that a combination of different storage options along the supply chain could reduce the total biomass storage cost for a biorefinery or power plant.

1. Introduction

Forest biomass and short-rotational woody energy crops are typically delivered to a biorefinery or a bioenergy plant in the form of chips, chunks, or logs [1–9]. The primary purposes of comminution are to reduce the particle size, homogenize the composition, and improve bulk density for easy transport, handling, storage, and to meet boiler or other conversion technology requirements [10]. Sawmill residues, shavings, and small diameter logs (less than 6 in.) are often used to densify into wood pellets that can be either used in a boiler to produce power, or produce liquid biofuel using biochemical or thermochemical conversion technologies. Woodchips or pellets are the most commonly-delivered form of woody biomass to biorefineries or power plants and they need to be stored along the supply chain with low material losses (i.e., dry matter loss) while keeping both the storage cost and GHG emissions low [11–14]. Fig. 1 shows the possible storage requirements along the biomass supply chain.

A typical biorefinery or a bioenergy plant requires a reliable, year-around supply of high-quality feedstock with consistent size, moisture content, and homogeneous compositions [13]. The typical moisture content of woodchips is in the range from 40% to 60% wet basis (wb) and high-moisture chips are susceptible to microbial degradation, if not immediately used, leading to high dry matter losses (DML) [12,15]. For a biorefinery producing liquid biofuel through biochemical pathway is unaffected by biomass moisture content [16]. But liquid biofuel production through thermal and biochemical conversion technologies require smaller size particles (< 2 mm) that require biomass (i.e., woodchips) grinding and milling [17]. The high moisture biomass demands higher energy for grinding and posses lower higher heating value (HHV) while increasing the handling and transport costs [18–21]. If a proper storage option is adopted, high moisture content feedstock can be dried naturally or artificially during storage. Therefore a well-designed storage system is required to reduce the dry matter loss (DML) and the feedstock delivered cost.

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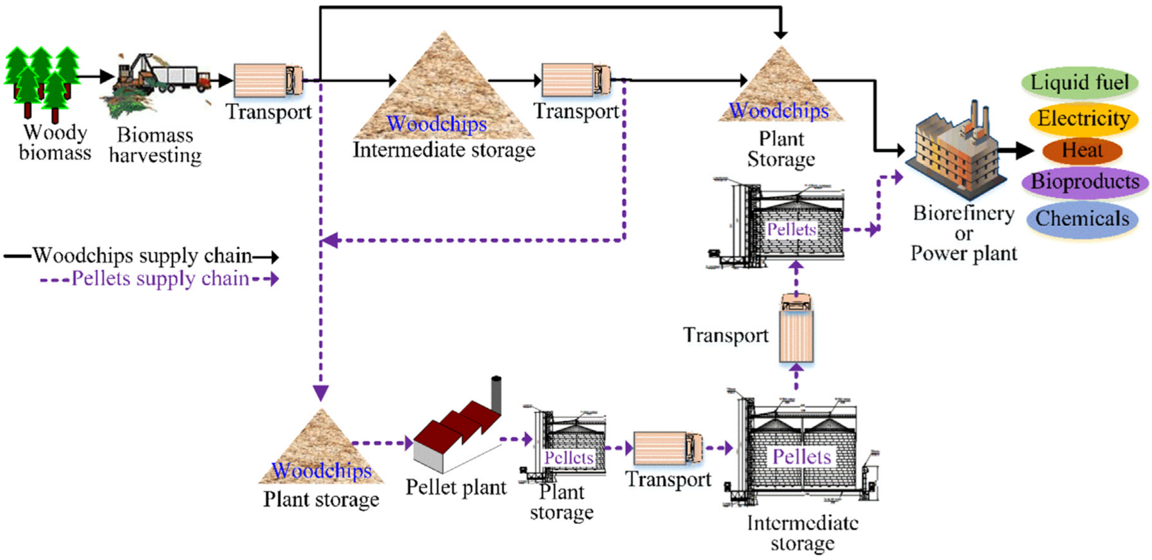

Fig. 1. Bioenergy/biofuel supply chain with potential locations for storing biomass.

Usually, low-bulk density woody biomass such as woodchips and sawdust are densified into high-quality pellets, which reduces the logistics and handling cost for long distance transport, e.g., between counties or sub-continents [18]. Pellet storage at the plants or along the supply chain serves as a buffer to minimize supply and demand uncertainties for consistent operation of a bioenergy plant [11]. Pellet storage costs can be lower than that of other feedstocks due to high bulk density and low DML. Therefore, biomass in the form of pellets can be a suitable option for long-term storage to counter supply disruptions to a biorefinery due to natural disasters such as drought, wildfire, etc.

Woodchips are typically stored in outdoor-open [22,23], outdoor-tarped [24–29] or indoor [30] systems. Pellets can be stored indoors or in silos either at a production facility, or at the point of consumption, or in between supply and demand points along the supply chain [31]. Silo storage can be used to store either woodchips or pellets. Indoor storage of woodchips is not preferred mainly due to high cost incurred for building permanent storage infrastructure. Outdoor-tarped woodchip storage can be preferable due to lower capital cost requirements and the flexibility to change storage locations [13]. However, the long-term storage of outdoor systems could increase the storage cost due to high dry matter losses (DML) [15].

Stored woodchips can emit a number of off-gases due to natural or microbial degradation. In addition to high storage cost, emissions from biomass storage can cause related to health hazards [34,35], the risk of fire [34,36] and greenhouse gas emissions [37]. Woodchips and pellets do emit carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (NO_x) and volatile organic carbons (VOC) during storage [15,38,39].

There is a multitude of factors that affect the emissions rate of stored biomass. They include the biomass type, initial moisture content, local storage temperature, rain/snowfall, relative air humidity, storage type, pile size, ventilation, location, and many more [14,15]. The GHG emissions may be much higher for outdoor storage compared to that of indoor or tarped storage options due to high biomass degradation exacerbated by high moisture content [37].

In the United States, paper and pulp industries incur millions of dollars lost every year due to the high rate of biomass deterioration/dry matter loss from short-term outdoor pulp-woodchips storage [40]. The financial losses from open storage of woodchips could be huge for bioenergy plants, triggered by dry matter losses and weather risks.

Large-scale bioenergy plants require a large and consistent biomass supplies for year around plant operations and longer-term biomass storage is unavoidable due to seasonal availability [41] and inclement weather that impedes harvest operations [42]. In Sweden, about 10% of the country's annual woodchip demand is stored for 5–10 months at energy conversion facilities [43]. Although forest biomass is available throughout the year, its accessibility is often limited due to climatic restrictions (i.e., spring breakup in northern states of the United States) [44], extreme weather (i.e., hurricanes, drought, wild fire etc.) [13] and seasonal timber harvesting restrictions (STHRs) [45], which can influence storage duration [8,34]. Therefore, it is important to design and choose appropriate storage systems [13] that offer low storage costs with minimal environmental GHG emissions. However, limited studies on storage of forest biomass, especially for woodchips and pellets are available in the literature. Woodchips and pellets storage costs and GHG emissions with respect to time, capacity, and storage type can be used by scientific communities and stakeholders to design supply chain networks for the biorefinery or power plant and to develop optimal storage strategies to reduce cost along the supply chain [13]. The objectives of this study were (i) to estimate the short and long-term storage costs and GHG emissions for woodchips and pellets using various storage options; (ii) to conduct sensitivity analysis on input parameters affecting the cost and environmental performance of storage systems; and (iii) to recommend appropriate storage systems for woodchips and pellets along the biomass supply chains.

2. Methodology

2.1. Storage methods

In this study, woodchips refer to comminuted forms of forest biomass from logs or forest residues. Pellets refer to densified biomass produced using pelleting technology mainly from sawdust or woodchips. Four primary storage methods were considered to store woodchips: (i) Outdoor-open, (ii) Outdoor-tarped, (iii) Indoor, and (iv) Silo (Fig. 2). Pellets are hygroscopic, that is they absorb moisture from the air, and they could disintegrate into powder, if stored outside. They are also a higher-cost feedstock than woodchips. Therefore, the only wood pellet storage systems considered were indoor bulk storage and silo storage.

In an outdoor-open storage facility, woodchips are in trapezoidal-shaped piles on the well-drained level ground. An outdoor-tarped storage facility uses a tarp [46] to cover an outdoor-open facility's trapezoidal woodchip piles from all sides [22]. An indoor storage facility for woodchips has a permanent roof structure with open sides and a well-drained floor i.e. pole barn [47]. However, an indoor storage facility for