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Review

Drywall (Gyproc Plasterboard) Recycling and Reuse as a Compost-Bulking Agent in Canada and North America: A Review

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Abstract: The incessant disposal of drywall waste, generated predominantly from construction and demolition sites, has been associated with many environmental problems. In landfill sites, it has long been linked with the generation of hydrogen sulphide, a toxic and foul-smelling gas, while the incineration of this waste results in the potential release of sulphur dioxide gas, a contributor to acid rain formation. The traditional disposal methods also result in the loss of a valuable resource. Therefore, proper management of this waste through recycling programs and subsequent returns to the end market will ensure that a valuable resource is not lost and that environmental impacts are mitigated. Many potential end markets have been identified for recycled drywall. The application as a bulking agent for composting is one of these markets, which could also provide additional calcium and sulphur nutrients to the soil. Despite the benefits of drywall waste recycling, certain challenges have crippled its recycling rate in North America. This review summarises the current situations with drywall recycling and disposal, existing markets, and the availability of competing markets. Furthermore, the potential use of drywall as a compost-bulking agent is discussed. Finally, a possible solution to improving the recycling rate and market demands for drywall is presented.

Keywords: drywall recycling; construction and demolition waste; bulking agent; composting

1. Introduction

Gypsum drywall, also referred to as wallboard, gyproc, or sheetrock, is mainly composed of 93% calcium sulphate dehydrate ($CaSO_4 \cdot 2H_2O$) and 7% paper [1]. It is an important interior wall material in North America for construction and remodeling. It is also an excellent fire barrier and hence applied in interior walls for both residential and commercial establishments [2]. In recent years, the generation of drywall waste has been on the rise in North America due to economic and population growth. The majority of this waste comes from both construction and demolition projects. On average, it is estimated that about a metric ton of drywall waste is generated from the construction of a typical single-family home of about 2000 square feet, while a 50,000-square-foot new office building generates approximately 16 metric tons of waste [1,3]. Between 496,000 and 585,000 tons of drywall waste is generated annually in Canada [4]. According to several characterisation studies on construction and demolition (C&D) debris in Canada, waste drywall accounts for about 9% of the mass of waste generated from C&D waste streams [5]. In North America, it comprises between 12% and 27% of C&D waste [6,7]. In general, waste drywall can be divided into three categories based on their source. (1) Manufacturing waste: This includes drywall waste that does not meet the required wallboard manufacturing specifications. It accounts for 12% of total waste drywall; (2) Construction waste: In North America, approximately 12% of new construction drywall is wasted during installation.

Drywall separation at the construction site is becoming a common practice, especially for large construction projects. Construction waste is the major source of waste drywall, accounting for 64% of the total; (3) Demolition waste: This includes both demolition and renovation waste, account for about 24% of waste drywall [8,9].

The disposal of drywall waste to the landfill is common practice in the past, even today. When disposed to the landfill, the moist anaerobic conditions of the landfill allow anaerobic microorganisms (sulphate reducing bacteria) to degrade the sulphate component of the drywall, producing potentially toxic levels of hydrogen sulphide gas [2,7,10,11]. Hydrogen sulphide is a flammable and extremely hazardous gas with a distinctive smell of a rotten egg. Consequent exposure to low concentrations can cause eye, nose, throat, respiratory system irritation, breathing difficulties, and headache. If ignited, hydrogen sulphide will be oxidised to sulphur dioxide, which is a known major contributor of acid rain. Acid rain is known for its negative impact on plant, aquatic, and animal life, as well as infrastructures. Drywall decomposition also results in an increase in the sulphate content in the landfill leachate, which could potentially contaminate both surface and groundwater. Excessive concentration of sulphate is of major concern in water supplies owing to its cathartic effect [12].

Owing to the environmental and public health concerns associated with waste drywall disposal, certain regions in North America have already banned the disposal of drywall in landfills. The Greater Vancouver Regional District and Toronto are two regions in Canada that have already banned its disposal to landfills, which has significantly improved drywall recycling in those regions. The Greater Vancouver Region recycles approximately 100,000 tons of drywall annually [3]. In 2010, the Massachusetts Department of Environmental protection banned the disposal of clean drywall scrap to the C&D landfill in the state due to the odour complaints from residents [13]. Many states in the United States have also long abolished the incineration of drywall waste [8].

2. Drywall Recycling

With numerous environmental challenges facing drywall disposal in the landfill, waste drywall recycling has been considered an important strategy to minimising this waste and consequently returning them back to end markets [14]. Generally, drywall waste that is generated from the manufacturing process and construction site is free of contamination or less contaminated. They are preferred material for recycling. However, drywall waste from demolition and renovation sites typically consists of certain contaminants. These include nails, tape, joint compound (primarily made from limestone or gypsum), and paint (structures built before 1978 may contain lead paint) [1,6,8]. The presence of these contaminants makes the recycling process complicated and costly. It is one of the challenges in waste drywall recycling.

Recycling drywall waste typically involves a collection of waste from manufacturing, construction, and deconstruction or reconstruction sites, and subsequent transportation to material recovery facilities (MRFs). At a MRF, drywall waste is sorted manually using a sorting belt to remove metals, plastics, and other debris. Drywall waste that is highly contaminated, for example, with mould and paint, unsuitable for the manufacturer's feedstock, is also removed. The minute ferrous metal fragments are removed from the sorted material by magnetic separation. The paper liner is separated from the gypsum core in an enclosed processing area. The recycled gypsum is then transported for use in a wide variety of applications [15]. After adequate recycling, the material contents are recovered, typically consisting of about 93% gypsum material, 6% paper, and <1% waste [10].

Currently, there are two drywall recycling facilities in Canada—the New West Gypsum Recycling (NWGR) and Recycle Gypse Quebec. NWGR, established in Langley, BC, in 1985, has developed into an international company with facilities across North American and Europe [3]. There are also a handful of drywall recycling facilities in the United States [2], including USA Gypsum, Gypsum Agri-Cycle, and Seattle Drywall Recycling Services. The listed drywall recycling facilities in North America currently accept all kinds of drywall scraps, except for Gypsum Agri-Cycle, which does not accept painted drywall.

3. Markets for Recycled Gypsum

Many potential markets have been identified for recycled gypsum, as shown in Table 1. However, the predominant markets identified for recycled gypsum in North America include drywall manufacturing and soil amendment. The majority of these end markets have very strict purity standards that only allow recycling facilities to accept clean scrap. As such, most drywall waste from demolition and renovation sites cannot be resold once recycled.

Table 1. Potential markets for recycled drywall [6].

End Markets	Specific Use
Drywall	Core material
Soil Amendment	Adds nutrients to soil for food growing, lawn and golf courses
Compost	As a bulking agent to compost materials
Cement additive	Added to control setting time and enhance capacity of radiant heat slabs
Stucco & planter	Used as an alternative for virgin material in this gypsum-based products typically made by gypsum manufactures
Wastewater treatment	Settle suspended clay particles in treatment process
Manure treatment	When mixed with ammonia, gypsum reduced odour from animal waste
Animal bedding	Helps to absorb moisture in bedding when mixed with wood shavings
Grease absorption	Can be sprinkled on top of oil leaks on auto shop or other industrial floors
Athletic field	Creates lines on football or soccer fields as an alternative to chalk
Dental moulds	Virgin material is used to make temporary moulds
Roadways	Facilitates the leaching of salts from soil along roads while ice melting

3.1. New Drywall Manufacturing

The use of recycled drywall for new wallboard manufacturing will help lower the need for virgin raw materials and reduce both energy and transportation costs. Drywall manufacturers have strict requirements for recycled gypsum incorporation into new drywall manufacturing. The paper content of drywall waste impacts the amount of recycled gypsum permitted for new drywall, as the paper content directly affects the fire rating [6]. Therefore, the separation of paper and other contaminants from drywall waste is desired by drywall manufacturers.

3.2. Land Application

Drywall waste from both construction and manufacturing has fewer contaminants and can therefore be recycled and used for soil amendment purposes. As soil amendment, it can be used for general agriculture, golf courses, mushroom growing, forestry and mine reclamation, nurseries, city parks and recreation areas, compost amendments, and residential lawns [8]. Gypsum from drywall is used to improve water penetration and the workability of an impermeable alkali soil. It is also very useful for agricultural purposes in improving both the poor soil physical properties and nutrient availability through the supply calcium and sulphur to the soil [6,16,17]. The calcium has also been reported to help flocculate clay in soil, hence providing favourable soil structure for root growth, air, and water movement [18].

4. Market Analysis for Recycled Drywall

New market opportunities (locally and regionally) and demand are the major driving forces towards sustaining the economic feasibility of recycled drywall. Strong demand is an important factor for any business establishment. Recycled materials with lower values and higher costs are generally not desired by customers without any regulatory body enforcing the choice for recycled materials. Despite the numerous end markets already identified for recycled drywall, the recycling rate for waste drywall in North America still remains at a very minimal level. Many factors contribute to this problem including low landfill tipping fees and low market demand.

4.1. Landfill Tipping Fees

Tipping fees are the predominant hurdles to recycling. It is also a major consideration for waste generators in making decisions regarding waste recycling or disposal in landfills in the absence of adequate recycling regulations or a landfill ban. Therefore, controlling the tipping fees and enforcing other conditions on the acceptance of wastes are strategic means to keep waste out of landfill [19]. The low tipping fee particularly in the United States has a hampered recycling rate of drywall within the region (North America), and recyclers find it extremely difficult to compete with the low fee [3]. Table 2 showcases some of the tipping fees of certain regions in North America.

Table 2. Landfill tipping fees in North America.

Country/City	Tipping Fee (CAD/t)	Source
Vancouver	133–150 [1]	City of Vancouver [20]
Kelowna	145	City of Kelowna [20]
Guelph	60	City of Guelph [20]
Calgary	80	City of Calgary [20]
Edmonton	42 [2]	City of Edmonton [20]
USA	44 [3]	Biocycle [21]

[1] $133/t for costumers with up to 2 sheets of drywall. $150 for over 2 sheets; [2] Clean and segregated drywall; [3] Based on the average tipping fees of all states.

In Europe, in addition to tipping fees, landfill taxes have also been enforced which has had a stimulating effect on the recycling industry. The high and increasing cost of landfill taxes has led to increased levels of waste recovery and a low reliance on landfill. The twenty countries in Europe that applied a landfill tax generated a total revenue of approximately €2.1 billion in 2009–2010. This revenue has been used to contribute towards general state and regional budgets, environmental initiatives, and waste management initiatives [22]. According to the European Environment Agency [23], The Netherlands has the highest landfill tax in Europe estimated at €107.50, while Sweden has the highest combined landfill charge (gate fee and landfill tax) at €155.50 (estimates based on the disposal of non-hazardous municipal waste). This high landfill fee in Europe has spurred the recycling rate in the region. For example, the recycling rate in Norway is estimated at 70% [22].

4.2. Market Demand

The demand for recycled drywall is influenced by several factors including (1) the cost of transportation, collection, and processing; (2) market availability; and (3) the existence of competing materials. Currently, the demand for recycled drywall in North America is low [3]. One of the most important reasons is the high cost of recycling drywall.

Though a number of markets have been identified for recycled drywall (Table 1), these innovative applications have not been widely employed in real practice. So far, wallboard manufacturing still remains the biggest market for recycled drywall. It has been reported that up to 25% recycled gypsum from New West Gypsum Recycling Inc. has been incorporated successfully for new wallboard manufacturing without any effect on quality [19]. Manufacturers typically set a limit for recycled drywall incorporation into new gypsum wall production due to quality issues as it might affect the productivity of gypsum board. Recyclers are often faced with technological challenges associated with the separation and processing of recyclable materials with mixed contaminants. Therefore, for an effective and high-quality recycling of post-consumer drywall to be accomplished, there should be mutual co-operation of a number of establishments, including waste collectors, recyclers, deconstruction contractors, and municipal governments. This will ensure the incorporation of higher percentages into new gypsum board.

The existence of a competing market has also limited the demand and recycling rate of post-consumer drywall. Synthetic gypsum, flue gas desulphurisation (FGD) gypsum, produced by FGD systems on coal-fired power plants, is a strong competitor for recycled gypsum. On an average, the production rate of FGD gypsum in Canada between years 2009 to 2011 was about 276,000 tonnes. A high percentage (99.3%) of the generated FGD gypsum was used for the manufacturing of new drywall, while the remaining percentage was incorporated into cement manufacturing [24]. In 2014, about 34 million tons of FGD gypsum was produced in the United States out of which 49% were used in different applications (Figure 1).

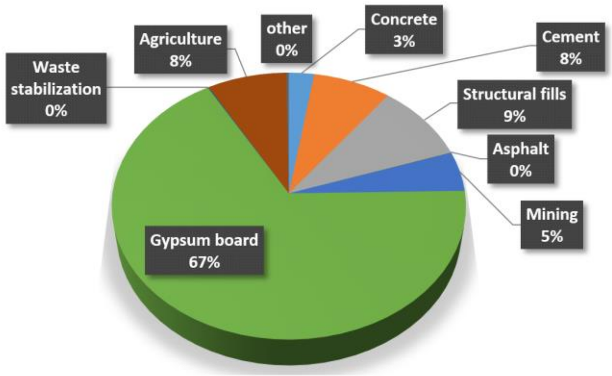

Figure 1. Percentage of FGD gypsum usage in the United States in 2014 [25].

In comparison to natural gypsum, FGD gypsum has a higher purity, usually around 96% to 80% of natural gypsum. In 2007, it was estimated that an average 44% of FGD was included in new wallboard manufacturing across Europe [26]. A recent report published by the USEPA has certified the use of FGD gypsum as safe; in terms of adverse environmental effects, no differences were found between FGD gypsum wallboard and natural gypsum wallboard [9]. Currently, high percentages of gypsum used in the manufacture of drywall in the United States come from FGD gypsum [27]. The low cost and ready availability of FGD gypsum in comparison to natural gypsum has encouraged drywall manufacturers to seek it and site their new plants close to coal-powered plants that produce synthetic gypsum. This has subsequently reduced transportation costs and fossil fuel usage. Currently, USG Corporation, a leading supplier of building materials to North American construction markets, currently incorporates more than 33% of FGD gypsum for drywall manufacturing. The percentage is expected to go up in the near future [20].

From the information gathered for the FGD gypsum, it might be difficult for post-consumer drywall to compete on the same playing field with the FGD gypsum. While high tipping fees and a landfill ban might accelerate its recycling rate, it could also pose a challenge for recycling companies without adequate technology for drywall recycling. This will in effect affect the cost of the recycled gypsum board. Therefore, it is the role of the government to create demand for it and provide funds for cutting edge technologies in order to improve the overall quality of recycled drywall at an affordable cost.

Addressing the issue of waste drywall from demolition and renovation sites is challenging due to the presence of contaminants including paper, paints, nails, screws, asbestos, etc. [1]. As such, most of them still end up in the landfill. To encourage recycling and reusability, deconstruction rather than demolition should be utilised. Deconstruction techniques would allow for the separation and subsequent recycling of materials including drywall.

5. Drywall as a Compost Additive/Bulking Agent

Application as a compost-bulking material is one of the potential end markets identified for recycled drywall. The growing demand for long-established bulking agents such as sawdust and woodchip as candidate raw materials for biofuel production has shifted interest into finding alternate bulking materials [28]. Therefore, recycled drywall could be co-composted with organic wastes such as municipal solid waste, biosolids, and animal manure.

Composting is a biological degradation process of organic material in a predominantly aerobic conditions forming a stabilised final compost free of phytoxicity and pathogens as well as supplying adequate nutrients beneficial for plant growth.

Composting generally provides solutions to the diversion of organic waste from landfill sites, thereby mitigating possible leachate occurrences, greenhouse gases emissions, odour generation, reductions in volume and moisture content, the stabilisation of organic matter, and, most importantly, the provision of high-quality fertilisers [29,30]. However, composting organic waste has proven to be very challenging as a result of high moisture contents and a lack of structure. This prevents free circulation of air and permeability within the compost pile, leading to potential odour generation and nitrous oxide emissions [31,32].

Hence, the use of bulking agents during the composting process will aid in bulk density adjustment, promote porosity and air void, balance the C/N ratio, provide sufficient aeration of composting piles while maintaining structure, and absorb excess moisture while sustaining microbial activity in the compost mix without inhibition [10,33,34]. The use of recycled drywall as a bulking agent will also supply valuable nutrients, including calcium and sulphur, which are beneficial for soil amendment purposes and plant growth [10]. This would prove useful in areas with scarce woody bulking materials and large amounts of grass clippings, and help to reduce the volume of waste dumped in landfills [1].

5.1. Studies on the Application of Drywall as a Bulking Agent

The incorporation of recycled drywall into a compost material for commercial land applications has not yet been developed. However, studies have suggested that its introduction does not interfere with either the composting process or the time of completion as a result of the sufficient biodegradation of drywall [35]. Very few studies on the use of recycled drywall as a compost mix have been reported. The published works have considered only clean drywall scrap from construction and manufacturing facilities and have not been treated with post-manufacturing coatings such as paint.

Saludes et al. [28] reported that using clean drywall scrap from manufacturing sites as a bulking agent for diary manure compost had no detrimental effect on the compost process after a period of 28 days. No phyto-inhibitory effects were detected at the end of the final compost with a germination index of 99%. The calcium level of the final compost increased significantly due to the presence of gypsum drywall. Another work has shown that the incorporation of clean drywall from construction sites to biosolids and manure composts, respectively, proceeded effectively with a significant increase in calcium and sulphur levels in the final compost. The study also showed that the application of drywall-biosolid compost to reclamation soils is likely to enhance response to plant biomass 7. Arnold [4] also reported that the co-composting of clean drywall scrap from construction sites with a combination of food waste, woodchips, and grass mixtures did not impede the overall composting process. The time for the compost completion proceeded as expected.

It is anticipated that the introduction of a bulking agent (gypsum drywall) will help control ammonia volatilisation in the form of nitrogen losses common to composting. The primary route for the nitrogen (N) transformation process in organic matter involves the mineralisation of organic N to NH_4^+ to NO_3^-, and subsequent denitrification of NO_3^- to N_2O and N_2 as shown in Figure 2.

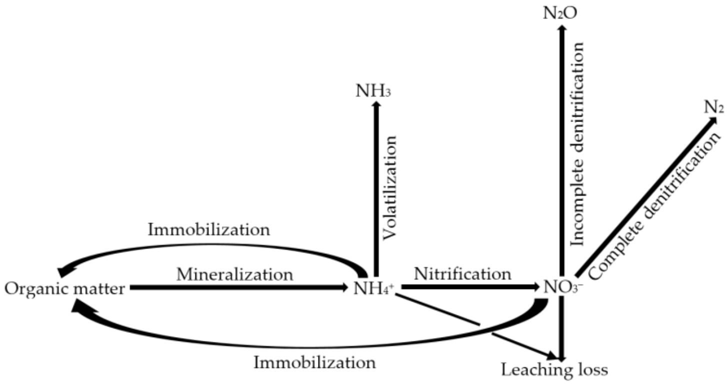

Figure 2. Pathway for nitrogen transformation during composting.

As the organic N is mineralised and given off as soluble NH_4^+ ions during the composting process, certain reaction pathways compete to transform the soluble NH_4^+ ions in the compost. These include the volatilisation loss as NH_3, immobilisation by microorganism, nitrification, and leaching. The major concern is loss through ammonia volatilisation (Figure 2). This ammonia loss during the composting process is not desired due to the association between the loss of nitrogen and a reduction in agronomic value of the final compost and potential odour generation [29]. About 50%–90% of all NH_3 losses have been reported to occur during the first few weeks of composting, which has been associated with a high temperature and pH [36]. Hence, when the gypsum drywall is blended into the compost mix as a bulking agent, the sulphate will attach to the ammonium molecules, forming a stable form of ammonium sulphate, which will prevent potential ammonia volatilisation. Tubail et al. [37] has reported some significant reductions of nitrogen in biosolids and dairy manure composts incorporated with FGD gypsum, which differ from the studies using gypsum drywall. Ammonia volatilisation during composting is particularly noted to be influenced by several factors, including ammoniacal nitrogen concentration, pH, temperature, moisture content, and aeration rate [38,39].

The electrical conductivity (EC) increased significantly when co-composting gypsum drywall with diary manure [7,28]. Electrical conductivity (EC) value greater than 4 dSm^{-1} as found in manure composts indicate excess salinity [40,41], which has the potential of inhibiting germination and plant growth [7]. An EC value less than 2.5 dSm^{-1} is recommended as a necessary growth condition for some plants [42]. Therefore, an adjustment of EC is necessary to avoiding plant growth inhibition. A possible method to the elimination of excess salt from the soil is through leaching with good drainage in place. An alternative method is the cultivation of salt-tolerant plants in the affected soil to accumulate the excess salt and the subsequent harvesting of plants to remove the salt from the area.

6. Future Prospects

Strong market demands and improved recycling for waste drywall in the near future still remain uncertain, but are achievable in North America. Many challenges have been identified for drywall recycling including low tipping fees, the existence of competing markets, high processing costs, and the presence of contaminants in waste drywall. Therefore, to overcome some of these pressing challenges and improve its acceptance in the market, there should be efforts by governments to create demands for the recyclables through education and public awareness, providing sufficient funds to recyclers to invest in cutting-edge technologies for drywall processing, in order to obtain high-quality products at a reasonable cost, and to impose a landfill ban on waste drywall. Generally, mutual co-operation of a number of establishments including waste collectors, recyclers, deconstruction contractors, and municipal governments will ensure that these challenges are met.

The use of gypsum from recycled drywall as a compost-bulking agent is one of the potential markets identified, but is still in its infancy. Several studies have shown that its incorporation into compost mixes did not affect either the composting process or the completion time ofcomposting. Additional calcium and sulphur were also provided by the gypsum and are beneficial for plant growth. However, the role of drywall in nitrogen reduction and the impact on greenhouse gas emissions require further study. Meanwhile, the EC value should be closely monitored, as this might result in plant growth inhibition.

7. Conclusion

Environmental concerns associated with waste drywall disposal are challenges that must be addressed. Waste minimisation through the diversion of drywall disposed in landfills to potential end markets will help reduce greenhouse gases emissions, odour generation, and energy costs for virgin materials, as well as the pressure on landfills to capacitate this waste. One of the potential markets identified is the introduction of gypsum drywall as a bulking agent during composting. Studies have shown that its incorporation might be beneficial to the overall compost process.

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