

MPCA C&D Landfill Cost Report

SSM 4506W: Sustainable Systems Management Capstone

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Introduction & Overview

Problem Statement

Construction and demolition (C&D) operations account for a significant amount of our waste streams, producing a staggering 1,534,127 tons in 2019 in Minnesota alone (MPCA, 2020). C&D waste comprises building materials and appliances originating from an industrial demolition site. Twice as much waste comes from C&D compared to household waste, and this number is only expected to grow, as an estimated one-third of existing buildings will be demolished by 2050 (MPCA, 2020). Currently, about 70% of C&D waste ends up in landfills (Hennepin County, 2024). It is hypothesized that landfilling C&D waste has additional environmental impacts from hazardous particulate matter emissions, eco-toxicity, and carbon emissions (Ecochain, 2024).

Melissa Wenzel, the Minnesota Pollution Control Agency's sponsor for this project, asked her colleagues a simple question: could anyone define the true cost of a cubic yard of construction waste? To her surprise, no one could answer this question, which is where our work comes in.

This project aims to identify the true environmental, economic, and social costs of a Construction and Demolition landfill in USD, for the Becker County Landfill in particular, from construction to closing. The traditional method of actualizing the costs of a landfill is expressed as the fee charged to those who dispose of waste in a landfill, otherwise known as a tipping fee. A traditional tipping fee covers various expenses, including operations, maintenance, regulatory compliance, and post-closure care. Still, it fails to include social and environmental costs, leading to an incomplete representation of the costs associated with waste disposal. Our analysis goes beyond the traditional tipping fee associated with C&D waste disposal. To identify environmental costs, we considered the greenhouse gas emissions released by the landfill and translated this to a monetary value through the social cost of carbon framework. Social costs

were assessed qualitatively by observing nearby community impacts, such as jobs generated by the landfill and decreased land value around the landfill.

Becker County Landfill has implemented a waste-diversion Reuse Program. In this program, materials fit for continuous use are salvaged from the waste and stored in a showroom warehouse where contractors, artists, and individuals can purchase the reused goods. Revenue generated and the mass of the avoided landfilled materials from this program will be incorporated into the overall cost characterization. This data, showing the economic value of Becker County's waste-diversion program, can be shared with other landfills to prompt their consideration of implementing a similar program.

Environmental Impacts

Climate change is an increasingly present issue our society faces and is only exacerbated by waste disposal in landfills. There are multiple negative externalities caused by landfills, including air pollution, the release of greenhouse gas emissions, water contamination and runoff, soil degradation, and habitat loss. Methane, an extremely potent greenhouse gas, is released into the atmosphere during the breakdown of materials in landfills, resulting in rising global temperatures at an alarming rate. The release of other greenhouse gasses, namely carbon dioxide and water vapor, contributes to climate change and the creation of smog (Vasarhelyi, 2021).

Many Minnesota landfills built before 1987, like the Becker County landfill, are not lined with high-density polyethylene plastic and tend to produce leachate, harming the surrounding environment. This leachate contains high levels of toxins such as ammonia, nitrates, and mercury, leading to water and soil contamination that harms local residents (Vasarhelyi, 2021). Excess nitrate runoff also causes eutrophication, degrading aquatic ecosystems and limiting plant growth (Vasarhelyi, 2021).

The construction of new buildings is incredibly resource-intensive. Of all the raw materials extracted from the earth, nearly 40% are used for construction, including 25% of all harvested virgin wood (Yeheyis, 2013). Resource extraction often releases high amounts of carbon emissions since heavy machinery powered by fossil fuels is currently the preferred extraction method. Extracting resources also comes with environmental concerns related to disrupting natural habitats.

The expansion of landfills contributes to habitat loss, and as of 2021, there were over 3,000 active landfills in the US that harmed 1,800,000 acres of habitat land (Vasarhelyi, 2021). Habitat loss and fragmentation are devastating to local ecosystems and contribute to biodiversity loss. This is important to note when considering things such as waste diversion programs, recycling, and deconstruction of buildings instead of demolition. These programs divert waste from landfills, elongating their lives and therefore, decreasing the rate at which landfills must be expanded.

Economic Impacts

Wastes from demolished buildings are typically considered to be void of value in the current linear economy, which is a key issue that leads to their disposal in landfills. As sustainability and responsible resource management become more prevalent values, various ways to divert these wastes from landfills are becoming more common. A large portion of waste generated by this industry has residual value and can be recycled or reused.

On average, large landfills decrease the adjacent land value by approximately 13%, while smaller landfills decrease the land value by 11.5% (Vasarhelyi, 2021). This is largely due to the social perception that this land is undesirable. This perception is not solely built from bias, as some valid concerns lead to this conclusion. These concerns include water quality, odor, smoke, noise, bugs, etc.

Social Impacts

The negative social and environmental impacts of C&D landfills are intertwined, as concerns such as air pollution and water contamination affect both human health and environmental health. From 2010 to 2017, MPCA evaluated groundwater impacts from 43 unlined C&D landfills across Minnesota to find 33 demonstrated significantly higher concentrations of arsenic in downgradient streams (Chiles et al. 2019). Arsenic in drinking water has severe health risks linked to cancer, skin lesions, cardiovascular disease, diabetes, and delayed cognitive development in youth (World Health Organization, 2022). Aside from these health impacts, as mentioned before, landfills also cause odor, smoke, noise, and bugs which disrupt local residents and decrease quality of life.

Environmental justice issues are extremely important to consider when identifying the true cost of waste disposal. Historically, landfills have had direct negative impacts on the lives of marginalized communities in the US. Construction and demolition landfills' impacts on water and air pollution are known to disproportionately affect low-income communities and people of color (Cannon, 2020). A study comparing socio-demographic relationships, such as race, class, and gender axes, between hazardous waste landfills and non-hazardous waste landfills found the percentage of the African American population significantly increases the likelihood of the county containing a C&D landfill (Cannon, 2020). These findings speculated a positive relationship between counties containing non-hazardous waste landfills while having a significant low-income and BIPOC population (Cannon, 2020). The study suggested similar externalities between hazardous and non-hazardous landfills.

Methods

System Description

The system analyzed in this project is the Becker County Landfill Complex, located in Detroit Lakes, Minnesota, serving 35,000 residents. **Figure 1** shows the landfill's location in the state of Minnesota. It includes a transfer station, a Municipal Solid Waste landfill, and a Construction and Demolition landfill. The focus area for our analysis was the C&D landfill. C&D waste includes building materials and appliances, such as concrete, gravel, shingles, brick, metal, wood, etc. Landfills are complex systems that are responsible for the disposal of solid waste. They are designed, operated, and monitored to comply with state and federal regulations to protect the environment and nearby residents from contaminants. They require physical inputs such as machinery, workers, waste, energy, and land to ensure the safe disposal of solid waste. They also produce negative externalities like leachate and various gasses, as noted in **Figure 2**. In this study, we assessed greenhouse gas emissions using the EPA's WARM model (EPA, 2015). The transportation and compaction of the C&D waste require fossil fuel inputs to operate heavy machinery.

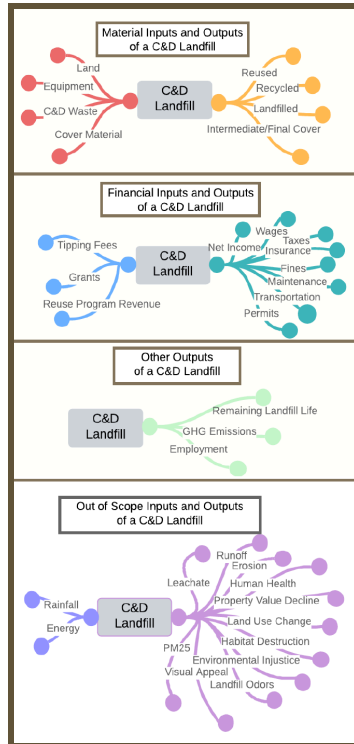


Figure 2. *Inputs and outputs of a C&D landfill, including materials, finances, and others.*

Many monetary inputs are required for permitting, labor, transportation, disposal fees, operation, machinery, maintenance, potential fines, and insurance. Landfill revenue is generated through grants, tipping fees, and sales from the Reuse program. To capture the complete social costs of the landfill, we incorporated the social cost of carbon and employment generated by the landfill. **Figure 2** shows the inputs and outputs covered in this report and which inputs are considered out of scope. Landfills are a necessary component of today's society, and they have vast social, economic, and environmental costs.

We inventoried and aggregated Becker County Landfill data from 2007 to 2023, specifically annual reports and landfill cell surveys. The annual reports are audits performed by the Becker County Landfill and given to the MPCA every year. These reports included the volume of the total waste received by the landfill (yd³), demolition waste that was landfilled, and demolition waste that was recycled or beneficially used. The demolition waste that was recycled or beneficially used was further classified into categories like the number of tires, major appliances, or cubic yards of concrete. The annual reports also included an estimate of the

remaining permitted operating life of the landfill in years. This is based on the amount of waste the landfill has received compared to its permitted capacity. While this lifetime estimate varies, it is still essential to determine the total landfill cost. A tipping fee per year was also provided. The tip fee is paid by anyone who disposes of waste in a landfill (\$/yd³). Total post-closure is provided in the annual reports as well. After the landfill closes, maintenance and upkeep will continue for many years, which is a cost that needs to be included in our analysis. **Table 1** shows the data aggregated for this project. This project was constrained by the data sets provided to us being focused on our specific project goal. Our data was very specific, which makes extrapolation difficult, and the performance of studies on other C&D landfills is necessary for a broader picture.

We assessed the potential climate change impacts of the landfill using the Environmental Protection Agency's Waste Reduction Model (WARM) (EPA, 2015). The WARM model estimates the metric tons of carbon dioxide equivalent, energy units in a million BTUs, labor hours, wages, and taxes associated with the C&D waste. This model estimates relative emissions associated with a baseline scenario compared to alternative waste management scenarios, including maximum recycling or maximum combustion options. WARM inputs include the volume and composition of C&D waste, as there is a wide range of environmental impacts depending on the material. We derived the waste volume from the annual reports data sets but had to make some assumptions when it came to composition. When considering the composition of the landfill's C&D waste, we used the percentages provided in the MPCA's *Construction and Demolition Materials Composition Study*, **Figure 3**. This study was published in 2020, and although it includes statewide data, it is the source that we determined to reflect the Becker County landfill's composition the closest. Before using these percentages to reflect the composition, we had to convert our data from cubic yards, a unit of volume, to tons, a unit of mass.

Costs from C&D Waste Carbon Emissions

We used the EPA's Waste Reduction Model (WARM) tool to calculate the environmental cost of producing carbon emissions related to landfill operations. WARM is a tool that can model carbon emissions, energy use, and financial costs of various waste management processes. This project used the carbon emissions feature within WARM to receive an estimated account of

carbon emissions from Becker County's C&D landfill. The EPA notes that WARM is not a holistic analysis of environmental damage (EPA, 2024). This model or study does not address other factors, such as water and air pollution from particulate matter.

To obtain our WARM model inputs, we extracted the yearly landfill volumes, given in cubic yards, from the landfill's annual reports between 2007 and 2023. The years 2016, 2017, and 2023 were missing information on the volume of C&D waste added in those respective years. A couple of assumptions were made for this analysis. First, we assumed the volumes in the report were uncompacted, therefore requiring a compaction factor, and second, that the volumes reported in the landfill were all diverted into the C&D landfill (i.e., no recycling or reusing the materials). Becker County reported volumes of C&D waste diverted into recycling in earlier reports. Our analysis did not consider these values because we lacked information regarding recycling volumes post-2015 and data on the types of materials diverted. Succinctly, we assumed that the entire C&D landfill volume in all of the annual reports went to landfill. **Table 2** shows the C&D intake quantities for each year and the average intake volume for the Becker County landfill, 22,863.28 yds³.

WARM model inputs are in metric tons and are broken down by material types. Therefore, the generic yearly volume had to be converted into WARM-compatible units. To do this, landfill material composition factors from the MPCA's 2020 *Construction and Demolition Materials Composition Study* were used to find expected volumes for different landfilled C&D materials. The Polk County Sanitary Landfill composition values of the MPCA's 2020 study, shown in **Table 3**, were used because both counties are in close proximity and had a similar reported population size (Polk: 30,412 people, Becker: 35,283) at the time of this study (United States Census Bureau, 2023b; United States Census Bureau, 2023a).

The volumetric units were converted by applying a representative density of each material group, applying a compaction factor of 0.25, and using the necessary unit conversion to convert the mass units to tonnes (Blankenship Equipment, 2017). **Table 4** shows the conversion process. **Table 4** also shows how the material groups from the composition study were fitted into the material groups available in the WARM model. The EPA's 2015 *Using WARM Emission Factors for Materials and Pathways Not in the WARM* document was to determine the WARM model category in some instances.

The Becker County Landfill provided additional data on the Reuse program's inflow volumes and composition. These values and the total composition landfill volumes were used to model three scenarios in WARM: maximizing landfill processing, maximizing recycling processing, and estimating the emission cost savings saved by the Reuse Program in 2023. Some materials are not commonly recycled; in these cases, a non-applicable option appeared for the recycling end-of-life (EOL) management method. In these occurrences, landfilling was selected as the EOL management method; therefore, in this sense, maximizing refers to managing the most waste material categories in the respective waste management method. To understand how the emissions translate into economic cost, we multiplied the emissions values by a conversion factor of \$190/ton of emissions, a factor recently updated by the United States EPA (Davenport, 2023).

Modeling Becker County's Waste Diversion and Reuse Program

As of 2020, in an effort to reduce waste, the tipping fee, generate revenue, and create gainful employment, the Becker County Landfill and Transfer Station partnered with Better Futures MN to create a waste diversion program, called the Better Futures ReUse Warehouse (BFMN RW). Here, in a warehouse facility adjacent to the Becker County C&D site, materials that are either donated by individuals, entities, or salvaged by workers from various on-site locations including the transfer station and metal pile, are upcycled into a variety of products and sold to consumers. A common example of this process would be scrap lumber being salvaged from the transfer station (TS), processed at the warehouse, and constructed into a bench to be sold to a consumer. Though the program is relatively new, it has been growing quickly, and modeling this growth can inform the potential costs and benefits of waste reduction practices.

To begin, because we only have three years of documented sale-logs for the BFMN RW, and only one year (2023) of data that can be easily quantified categorically on a spreadsheet, it is important to recognize the limitations of this data and draw assumptions when formulating our methodology. To begin, due to 2023 being the only year where re-use sales were broken down categorically by item type and origin location, for the sake of modeling this data, we will assume that every operating year of the program, both past and future, follows the same ratio of material types and origin locations as 2023. Another assumption will be that the end-of-life for all items sold by the BFMN RW would have been in the C&D landfill. Realistically, because the site

operates as a transfer station for municipal solid waste (MSW), C&D waste, household hazardous waste (HHW), recycling, organics and a number of other waste types that require case-by-case end of life locations, many of the items sold by the RW likely wouldn't have been deposited in the C&D landfill. However, it would be impossible to quantify the true end-of-life location for these unless this had been previously documented. The third assumption in our methodology will be that all item types fall under the same volumetric compaction factors and waste type makeup as the EPA's National Recycling Coalition Measurement Standards and Reporting Guidelines (EPA, 2006). This assumption will be important, as later discussed, when modeling both the current and future cost reductions for the C&D landfill through standardizing the compaction volume of upcycled materials. For example, a metal shelf sold by the BFMN RW that weighs 225 pounds will be categorized as "Scrap Metal" with a compacted volume of 1 cubic yard (EPA, 2006). Although many of the items sold can't be quantified with an exact compaction volume, this will be our best method to see the positive impacts of this program on the C&D landfill (tipping fee reduction, increased life expectancy, etc). The final assumption for this methodology is that our estimated landfill closure date will be unimpacted by BFMN RW growth. Realistically, as this program expands, it will continuously increase the life expectancy of the C&D landfill as more volume of waste is diverted, but due to uncertainty this will be too difficult to calculate and would not be a reliable metric for our end-of-life expectancy calculation.

To begin this methodology, data was modeled from 2023 to show the breakdown of item quantity, total weight, and total revenue for each material type and origin location. These breakdowns can be seen in **Figure 11a** and **Figure 11b**. With these metrics, we then broke down each material type and origin location by item count and item weight, we compared the percentage makeup of each category to its generated revenue percentage in order to determine the profitability relationships for each. These relationships can be found in **Table 5** and **Table 6**, and will serve as an important resource to see how the BFMN RW should best delegate their resources as the program expands, depending on constraining factors such as labor and remaining landfill volume.

As mentioned previously, we only have detailed material-type breakdown data for 2023. However, we can use this in conjunction with net weight and sales revenue to estimate similar

parameters for previous years. From the provided data in 2023, we've modeled both logarithmic and polynomial forecasts for what the next 10 years may look like in terms of each metric. While the polynomial curve shown in **Figure 12b** is the most accurate fit for the current data points, it is unlikely that this volume of upcycled material will grow at an exponential rate due to facility and labor capacity and consumer demand. Therefore, for the modeling of future BFMN RW growth, we will use logarithmic trendlines as this represents the most realistic trend given our limited data, as seen in **Figure 12a**. Due to the element of uncertainty in these projections, we will also model zero-growth revenue and C&D reduction scenarios, which will be a summation of our current data and the repeating data from 2023 forecasted until the C&D landfill's estimated closure date.

In order to assess the C&D landfill's hypothetical cost savings from the volumetric reduction of waste diversion, we have modeled both low and high-case scenarios using the most common C&D and MSW material streams in the US. In the two models shown in **Figure 13a** and **Figure 13b**, the annual weight of the six largest material types is quantified by using the EPA's National Recycling Coalition Measurement Standards and Reporting Guidelines, a standard benchmark for converting weight to volume for the most common C&D materials in the US (EPA, 2006). Each model assumes constant linear growth of the program based on our logarithmic forecast. The high-end forecast noted in **Figure 13a** accounts for low material density and high volume (such as uncompacted lumber pallets), while the low-end forecast noted in **Figure 13b** accounts for high density and low volume items (such as compacted clean fill wood). As previously mentioned, the EPA's weight-to-volume conversion tool only covers certain material varieties, so although this isn't the most realistic way of mapping the volumetric reductions of case-by-case items, creating a low-end and high-end scenario will give us a general upper and lower bound for the actual volumetric reduction from this material.

Operation Costs

A financial analysis was used to assess the economic cost of landfills. For the financial analysis, Steve L. Skoog provided an income and expenses file relating to the landfill's operations and percentages attributable to C&D operations for different accounts, as shown in Table 7. We used an expense account, not net profits, to find the true tipping cost at the

landfill. We used the US Bureau of Statistics CPI to adjust all the years' expenses from 2007 into 2023 USD. Finally, the yearly total expenses were averaged to obtain an expected yearly expense for our further calculations.

Social Costs

In efforts to quantify the social impacts of the Becker County C&D landfill, we initially assumed this would be best understood through the public health perspective. After researching the public health impacts of C&D landfills across the US and in Minnesota, data and case studies were minimal. Since this data was unavailable and lacked the methodology to express such impacts in USD, we excluded it from our final cost analysis.

Quantifying social impacts proved challenging, and our group decided to assess social costs through a qualitative analysis. To do so, we contacted Becker County Landfill staff to seek out individuals who would be interested in being interviewed to understand residents' opinions and interactions with the landfill. Sandy Gunderson, who manages public outreach for the landfill, provided a list of 3 Detroit Lakes residents and active community members. After receiving their contact information, our group reached out to schedule interviews, and 1 of the 3 individuals agreed to be interviewed. While this process also did not affect our final cost analysis, residents' insights helped develop recommendations for the Becker County C&D Landfill.

Calculating Tipping Cost

Two methods were used to determine the cost per cubic yard of landfill. This was done to provide a range for some variability in the landfill's operation. Method 1 uses inputs that reflect variability, while Method 2 uses fixed values. Method 1 accounts for variability in closure years and yearly landfilling volumes. Method 2 accounts for the passage of time in the reports and uses the ultimate landfill capacity constant of 491,000 yd³ of the landfill. Both methods find the true tipping cost by compounding the different costs of the landfill during its operating life and dividing that value by the volumetric capacity of the landfill to obtain the cost per cubic yard (\$/yds).

Figures 6 - 10 are derived from data included in the annual reports and the income and expense sheets and were used to determine values for method one, which calculates dollars per

cubic yard of landfill. While annual tipping fees vary over the lifetime of a landfill, we found the average annual tipping fee to be \$9 USD per cubic yard **Figure 6**. The average total post-closure cost is \$601,481 USD, expressed in **Figure 7**; the average demolition waste landfilled per year is 22,860 cubic yards, expressed in Figure 8, and the average remaining ultimate operating life is 25.4 years, seen in Figure 9. By adding the average years remaining reported in the annual reports between 2007 and 2023, 25.4 years, to 2024, we can estimate the year the landfill will close, 2049.4. The landfill began operations in 1993. Therefore, the total operating life would result in 56.4 years using this operating life determination method. The final closure date of the landfill incurs a lot of variability, so a secondary method was performed to obtain a secondary estimate of the total years of operation. In this method, we added the remaining life to the year from which the report was extracted. This gave us a list of expected closure years. Then, the closure years were averaged to obtain an expected closure of 2037. This method for obtaining an expected operating life is shown in **Table 9**. Considering again that the landfill began operation in 1993, resulting in a total operation life of 44 years.

The final important cost to note is the initial cost of purchasing the land used for the landfill, which was \$27,500 in 1987, equivalent to \$76,000 in 2024.

Results

Costs from C&D Waste Carbon Emissions

Figure 5 shows the first model, which shows the current assumed state of the landfill, where all C&D waste enters. This graph shows that most emissions produced in the life cycle of C&D waste materials occur during the production process, shown in blue. The emissions from landfilling, shown in red, are low because materials in C&D waste piles, such as concrete, metal, and glass, tend to be inorganic. Also, concrete, copper, and aluminum are the highest emitters of emissions in the lifecycle of C&D waste.

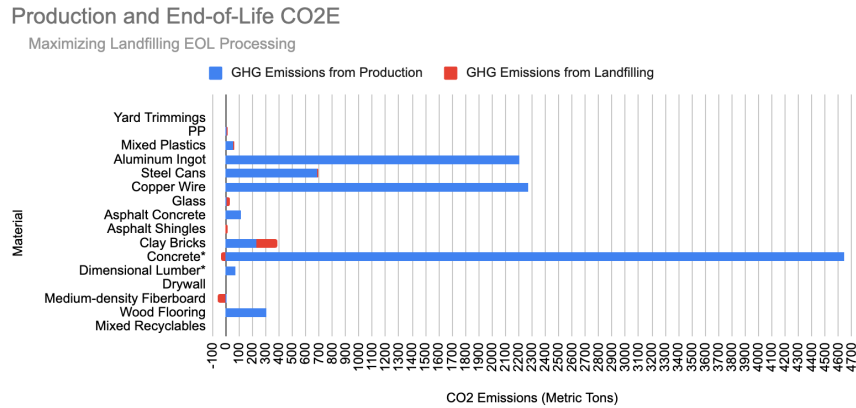


Figure 5. Bar graph showing emissions from the production of waste materials and at the landfilling EOL.

Figure 6 shows the recycling model's maximization, where recycling materials are maximized. Yellow indicates the net emissions from the recycling process, and blue and red indicate emissions from production and landfilling. Landfilling emissions in this model were small enough not to appear in the graphic representation. Note that the emissions from concrete production remain the same and that recycling metals such as aluminum, steel, and copper are the most impactful for curbing emissions.

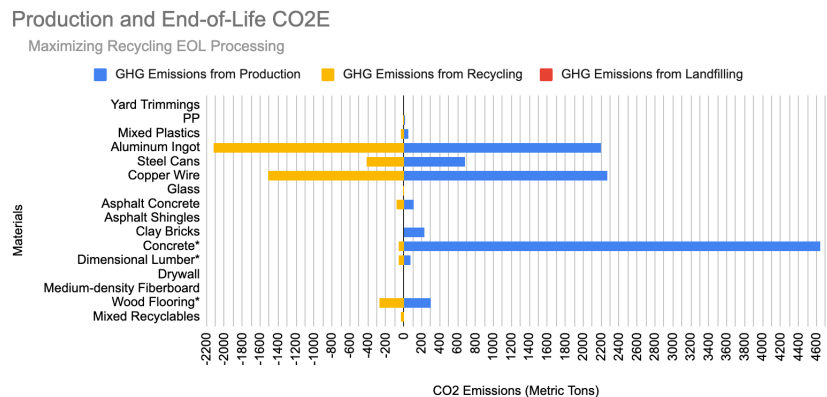


Figure 6. Bar graph showing emissions from the production of waste materials and at the recycling EOL.

Figure 7 shows a visual representation of the REUSE program's 2023 emissions. The red lines indicate the emissions that would have been produced if the materials had been landfilled. Again, the emissions from landfilling are small and barely noticeable on the graph. The blue demonstrates the net CO₂E from a source reduction alternative, i.e., the emissions saved from avoiding producing new materials. Becker County's REUSE program has effectively reduced emissions caused by mixed metals and plastics.

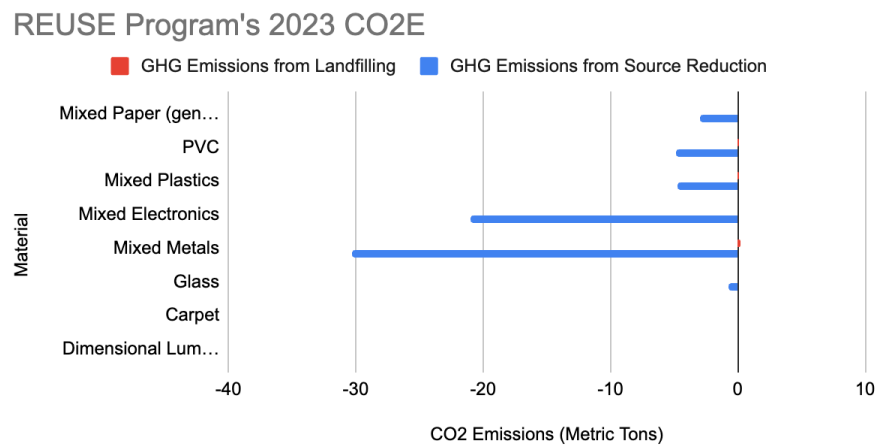


Figure 7. *Net emissions of Becker County's Reuse program.*

Tables 8a, 8b, and 8c show the CO₂E metric ton volumes and subsequent social costs of carbon (SSC) for each model. Our cost findings from this analysis are as follows: The total SSC of an average year of landfilling at the Becker County landfill is **\$2,035,731.44** dollars, and the total cost of SSC would be **\$1,143,303.34** if the landfill were to prioritize recycling their waste materials. The majority of the cost in both scenarios comes from the production of the waste material, the cost being **\$2,014,326.04** dollars for both scenarios (recycling creates a deficit cost, i.e., savings).

In modeling the REUSE program's 2023 diverted volumes, we notice that the landfill saved \$64.60 dollars from EOL emissions. The costs saved from producing new materials, **\$12,296.80 USD**, is far more notable, especially considering that the program had only been running for 3 years at the time of this report.

Operation Costs

The value obtained for the expected yearly expenses associated with the financial analysis's C&D operations was **\$4,200,421.25 USD**. The yearly expense value factors are included in our final cost analysis equation in the *Final Results* section of this report.

Social Costs

Through conducting interviews with a Detroit Lakes resident, we identified qualitative costs and benefits associated with the Becker County Landfill. Nearby land is considered “undesirable” by residents and has a lower property value than other neighborhoods. This resident, in particular, was unaware that landfills are unlined and that this may affect groundwater. The interviewee shared that their drinking water has high levels of arsenic and did not attribute this to the landfill specifically but suggested non-human causes. A qualitative benefit is that the Material Recovery Facility employs recently incarcerated individuals to develop workforce skills. The Better Futures Reuse Program also offers access to high-quality materials such as furniture, construction materials, appliances, etc.

Final Result Method 1

$$\frac{[(56.4 \text{ yr} * 420,041.25 (\$/\text{yr})) + (56.4 \text{ yr} * 21,405.4 (\$/\text{yr})) + \$601,481 + \$76,000]}{(22,860 (\text{yd}^3/\text{yr}) * 56.4 \text{ yr})} = 20 \$/\text{yd}^3$$

This is more than two times higher compared to the average tipping fee.

Final Result Method 2

$$\frac{[(44 \text{ yr} * 420,041.25 (\$/\text{yr})) + (44 \text{ yr} * 21,405.4 (\$/\text{yr})) + \$601,481 + \$76,000]}{(491,000 \text{ yd}^3)} = 40 \$/\text{yd}^3$$

This is more than four times higher than the average tipping fee.

Modeling Becker County's Waste Diversion and Reuse Program

Sales Revenue:

As seen in **Table 5** and **Table 6**, both item count and item weight from the various origin locations and material types of the 2023 reuse sales are compared to the revenue generated, with positive relationships highlighted in green. In **Table 6**, it can be seen that by quantity, items salvaged from the metal pile are the most profitable, generating ~\$7,500 in 2023, translating to \$208,149.27 in total profit from 2020 to 2049 in a zero-growth scenario when utilizing the expected operating life of Method 1, and \$874,748.94 in total profit with a logarithmic growth projection. However, as seen in **Table 5**, by weight, the transfer station is the most profitable, indicating that these items create the most revenue with the least amount of weight. In 2023 alone, the transfer station accounted for 72.6% of the ReUse program's revenue (\$11,400.97), meaning that in a linear growth projection, salvaging items from the transfer station at the same rate will have generated over \$1.1 million in revenue.

When looking at the total sales revenue of the BFMN RW (without accounting for labor and facility costs), in 2023 alone, the BFMN RW was able to divert 33.71 tons of waste, generating a direct revenue of \$21,257.04, a number which is expected to increase each year. However, in order to minimize uncertainty, even in the scenario that the program doesn't grow and remains generating the same revenue as 2023, it will have generated \$601,590.91 by the expected landfill closure date.

Cost Reductions:

As seen in **Figure 13a** and **Figure 13b**, both hypothetical compaction scenarios result in significant C&D volumetric reductions by the 2049 expected date of closure. In the low-end scenario, the cumulative reductions will have been 18,947.32 yd³ by the landfills estimated closure date, and in the high-end scenario it will have been over 100 thousand yd³ by the closure date. Though these scenarios present a large range of uncertainty, due to their quantification of both material density and compaction rate extremes, a realistic reduction will fall somewhere in between these two volumes. In a low-end scenario, assuming the Method 2 true cost of \$40 per yd³, this will have caused an estimated cumulative cost reduction (CCR) of \$757,892.80, and a CCR of ~\$4.26 million in a high-end scenario. This correlates with the equivalent volume of

~171 3000ft³ shipping units in the low-end model, and almost 1 thousand shipping units in the high-end model. Assuming the average waste per year volume of 22,860 yd³/yr, the low-end model has potential to increase the life expectancy of the landfill by 303 days, and the high-end model will increase the life expectancy by 4.66 years. In a zero-growth scenario, the BFMN RW will reduce the volume landfilled by 22,503.01 yd³ by the closure date, which is almost exactly one year of landfill operation (359 days), reducing operational costs by ~\$900 thousand.

By additionally utilizing the WARM model over this twenty-nine year period, this would have an equivalent SCC reduction of \$1,873.40 from GHG emissions caused by landfilling, and an SCC reduction of \$356,607.20 caused by the virgin manufacturing of these materials, when neglecting to account for the GHG emissions produced during the upcycling process at the BFMN facility. When accounting for both direct revenue generated and the SCC environmental cost reductions of the ReUse program, even in the scenario where the program doesn't grow during the next decade, it will have generated just over \$960 thousand in cumulative revenue, along with creating additional gainful employment for members of the correctional facility.

Assuming a landfill closure date of 2049, and the true cost of landfilling of \$40/yd³, when taking into account direct sales revenue, landfill volume input reductions, GHG emissions reductions, and SCC reductions, the cumulative cost savings from the BFMN RW will be ~\$1.86 million by the expected closure date in a zero-growth scenario. In reality, these savings benefits will be much greater as the program is expected to continue its expansion. Furthermore, this is only a fraction of the true zero-growth revenue and CCR's, and further quantification of social cost benefits (such as gainful employment and co-beneficiary labor partnerships), scope-3 emissions reductions from reducing virgin manufacturing, local environmental benefits (hazardous groundwater leachate reductions, etc), transport emissions reductions, landfill life expectancy increase, and more. The list is endless, and the true zero-growth CCR estimate is likely much higher.

Conclusions and Recommendations

The WARM analysis portion of this study shows that most emissions in the C&D waste's life cycle come from the production period. This emphasizes the importance of keeping materials

in circulation to reduce the necessity of producing new materials. This is especially important for the building's cement foundation and metal installation portions. This study highlights the importance of facilitating the design of new structures that optimize the existing foundations and materials. Further discussions could develop on the importance of educating and training professionals in the field to perform remodels safely and efficiently.

We have found that the cost per cubic yard of demolition landfill is \$20-40 which is significantly higher than the usual tipping fee of \$9 per cubic yard charged by the Becker County Landfill. Method 1 gave the lower result of 20 \$/yrd³, and Method 2 gave the result of 40 \$/yrd³. Method 1 has more variability because it is projecting the future based on current data we have been given, while method two is more stable, because it is based on numbers we know, but this also makes it less flexible. What we are seeing is an underestimate of the true costs of a landfill over its lifespan, which can cause negative externalities. This can lead to potential social, environmental, and economic costs caused by increased waste disposal. Health impacts, higher greenhouse gas emissions, and high landfill subsidies are specific examples of these negative externalities. Some of these costs are offset by the BFMN RW which merits continued data collection to document its overall value to Becker County as well as allowing for avoided greenhouse gas emissions and associated costs to the public.

Through our analysis, we determined the social costs of the C&D landfill cannot be expressed in USD at this time. This is due to the inability to estimate the costs of intangible disruptors such as human health impacts, noise, and odors. The Becker County landfill employs previously incarcerated individuals at their material recovery facility, which allows them to gain professional development after experiencing hardship, adding societal value through gainful employment. This program has not been included in our final cost analysis as it is outside the scope of the C&D landfill. The Reuse Program through Better Futures MN, which receives valuable C&D waste from Becker County Landfill, also has a workforce development program. As this program continues to grow, understanding the relationships between item quantity, material type and origin location is important for knowing how to most efficiently operate the program. We found that metal was the most profitable material type by quantity, and plastic was the most profitable by weight. This information is useful because it means that if labor is a constraining factor for the Reuse Program, emphasis should be put on upcycling items from the

metal pile. However, by weight, plastic is more profitable since these items are typically low in density and, therefore, should be prioritized if labor is abundant and the goal is to best reduce landfill volume. Even with our limited scope, finding the zero-growth CCR of the BFMN RW to be ~1.86 million by the end-of-life closure date shows that this program will play an incredibly vital role in just about every way, shape and form, and should not only be expanded but should become a standard for any C&D landfill in which it's feasible.

To expand our ability to better account for the true costs of landfills in general, increased data collection on social impacts, specifically regarding groundwater quality, air quality, and researching other effects on landfill adjacent neighborhoods is recommended. In the future, the landfill should include information on the composition of C&D waste in their annual reports. Although we were able to find statewide information on the composition, it could be very helpful to know the composition of the site specifically. This could be useful in understanding the Reuse Program and in analyzing how different percentages of waste may vary over time with the addition of such a program. The true CCR of the Reuse Program should be examined with a larger scope and greater detail, in order to get a broader understanding of the benefits of this, and incentivise the expansion and normalization of similar programs. Lastly, to get a more accurate representation, design and construction expenses of the landfill are necessary to compute the true costs.

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Team Acknowledgments

Will Barford: Calculating Tipping Cost, Final Result Methodology, Conclusion and Recommendations

Ana Figueroa Arteaga: Costs from C&D Waste Carbon Emissions, Operation Costs, Calculating Tipping Cost, Final Result Methodology, Conclusion and Recommendations

Madelyn Kinny: System Description, Conclusion & Recommendations, Problem Statement

Katie Nesheim: Introduction & Overview, Social Costs, Conclusion & Recommendations, Results, Methods

Russell Williams: Modeling Becker County's Reuse Program, Conclusion & Recommendations

Appendix

Table 1

Waste received & disposal capacity per year

	2007	2008	2009	2010	2011	2012
Waste Received						
Total Waste Received (Yrd ³)	28690.5	20,438.70	19595.13	22842.15	21368.92	21518.5
Demolition waste landfilled (Yrd ³)	22135	19,632.50	17783.88	21456.95	20041.92	16932
Demolition waste recycled or beneficially used (Yrd ³)	6555.5	806.25	1811.25	1385.2	1327	4586.5
Disposal Capacity (waste disposal area: demolition)						
Permitted capacity (Yrd ³)	298000	298000	298000	298000	298,000	298,000
Capacity actually used in Year (Yrd ³)	9850	8538	11952	8800	8300	6,278
Remaining permitted capacity (Yrd ³)	96707	76169	64217	55417	47117	40,851
Ultimate capacity (Yrd ³)	491,000	491000	491000	491000	491000	491,000
Remaining ultimate capacity (Yrd ³)	277,707	269169	257217	248417	240129	233,851
Remaining ultimate operating life (years)	28.19	31.53	21.52	28.23	28.93	37.25

Table 2

Yearly intake landfill volumes extracted from Becker County's Landfill annual report

Year	Total C&D Landfill Volume (CU. YDS.)
2007	28,690.50
2008	20,438.70
2009	19,595.13
2010	22,842.15
2011	21,368.92
2012	21,518.50
2013	24,711.00
2014	29,222.00
2015	24,627.00
2016	
2017	
2018	25,357.00
2019	12,417.00
2020	23,151.00
2021	23,105.00
2022	23,042.00
2023	
Average	22,863.28

Note. Years 2016, 2017, and 2023 are missing data.

Table 3

Becker County 2020 Composition study of Polk County's C&D landfill.

Table 16. Polk County Sanitary Landfill detailed facility results by Material

Material	Tons	Percent	Material	Tons	Percent
Concrete	156.5	56.4%	Gypsum Board	9.7	3.5%
			Gypsum Wallboard - Clean	1.6	0.6%
Roofing Shingles	2.2	0.8%	Gypsum Wallboard - Painted	8.1	2.9%
Brick	25.5	9.2%	Clean Wood	3.8	1.4%
			Untreated Dimen. Lumber	2.5	0.9%
Dirt/Sand/Rock/Gravel	37.4	13.5%	Untreated Eng. Wood	0.5	0.2%
Dirt/Sand	27.7	10.0%	Wood Pallets/Crates/Spools	0.8	0.3%
Rock/Gravel	5.8	2.1%			
Yard Waste	3.9	1.4%	Metal	7.8	2.8%
			Appliances	0.0	0.0%
General C&D	25.0	9.0%	Composite Metal (wires)	0.2	0.1%
Acoustic Tiling	0.5	0.2%	Ferrous Scrap	1.8	0.6%
Asbestos*	0.0	0.0%	Non-Ferrous Metal	5.8	2.1%
Asphalt	0.2	0.1%			
Carpet	0.1	0.0%	MSW	0.1	0.0%
Carpet Padding	0.0	0.0%	Bulky Items (inc. mattresses)	0.0	0.0%
Ceramics/Porcelain Fixture	0.2	0.1%	E-Waste	0.0	0.0%
Flat Glass	0.2	0.1%	MMSW	0.0	0.0%
HVAC Ducting	0.0	0.0%	Other Paper	0.0	0.0%
Insulation	0.0	0.0%	R/C and Other Glass	0.1	0.0%
Plastic Piping	0.0	0.0%	Tires	0.0	0.0%
Plastic Siding/Decking	0.1	0.1%	Uncoated OCC - Recyclable	0.0	0.0%
R/C and Other C&D	23.6	8.5%			
Rubber Products	0.0	0.0%	Plastics	0.5	0.2%
Tyvek Building Wrap	0.0	0.0%	Durable Plastic Items	0.0	0.0%
			Film Plastic (Comm./Indus.)	0.0	0.0%
Treated/Painted/Processed Wood	9.0	3.3%	HDPE Buckets	0.0	0.0%
Painted/Stained Wood	8.7	3.1%	Plastic Furniture	0.0	0.0%
Treated Wood	0.0	0.0%	R/C and Other Plastic	0.5	0.2%
Wood Furniture	0.3	0.1%			
Number of Scaled Loads	30		Scaled Tons Surveyed	277	
Number of Estimated Loads	0		Estimated Tons Surveyed	0	

*Pursuant to an approved ISWMP.

Visual characterization was conducted on tipped loads. Following classification, facility staff removed anything within the load that was unacceptable to be disposed there.

Table 4

Calculations converting expected landfill inflow volumetric units to mass units to be used as inputs for WARM

Polk County Sanitary Landfill detailed facility results by Material								
Material	Density	Unit	Compaction Factor	Percent	Expected Volume of Waste (CU. YDS.)	Tons of Waste	Used in Warm or Not	Entered in Warm as
Concrete	2,400.00	kg/m³	0.25	56.40%	12894.88911	6515.779218	✓	Concrete
Roofing Shingles	15.00	kg/m³	0.25	0.80%	182.9062286	0.5776400016	✓	Asphalt Shingles
Brick	1,920.00	kg/m³	0.25	9.20%	2103.421629	850.2860824	✓	Clay bricks
Dirt/Sand/Rock/Gravel				13.50%	3086.542607			
Dirt/Sand	1,600.00	kg/m³	0.25	10.00%	2286.327857	770.1866688	✓	Asphalt Concrete
Rock/Gravel	2,400.00	kg/m³	0.25	2.10%	480.12885	242.6088007	✓	Asphalt Concrete
Yard Waste *(lbs / CU.YDS.)	227.00	lbs / CU. YD	0.25	1.40%	320.0859	9.082437413	✓	Yard Trimmings
General C&D				9.00%	2057.695071			
Acoustic Tiling	165.00	kg/m³	0.25	0.20%	45.72655714	1.588510004	✓	Medium Density Fiberboard
Asbestos*			0.25	0.00%	0	0		
Asphalt	721.00	kg/m³	0.25	0.10%	22.86327857	3.470653676	✓	Asphalt Concrete
Carpet	105.00	kg/m³	0.25	0.00%	0	0		
Carpet Padding	160.20	kg/m³	0.25	0.00%	0	0		
Ceramics/Porcelain Fixture	2,400.00	kg/m³	0.25	0.10%	22.86327857	11.55280003	✓	Mixed Recycling
Flat Glass	2,580.00	kg/m³	0.25	0.10%	22.86327857	12.41926003	✓	Glass
HVAC Ducting	24.00	kg/m³	0.25	0.00%	0	0		
Insulation	32.00	kg/m³	0.25	0.00%	0	0		
Plastic Piping	1,450.00	kg/m³	0.25	0.00%	0	0		
Plastic Siding/Decking	1,377.00	kg/m³	0.25	0.10%	22.86327857	6.628419018	✓	PP
R/C and Other C&D	3,000.00	kg/m³	0.25	8.50%	1943.378679	1227.485003	✓	Concrete
Rubber Products	1,522.00	kg/m³	0.25	0.00%	0	0		
Tyvek Building Wrap				0.00%	0	0		
Treated/Painted/Processed Wood				3.30%	754.4881929			
Painted/Stained Wood	500.00	kg/m³	0.25	3.10%	708.7616357	74.61183354	✓	Wood Flooring
Treated Wood	500.00	kg/m³	0.25	0.00%	0	0		
Wood Furniture	500.00	kg/m³	0.25	0.10%	22.86327857	2.40683334	✓	Dimensional lumber
Gypsum Board				3.50%	800.21475			
Gypsum Wallboard - Clean	10.20	kg/m³	0.25	0.60%	137.1796714	0.2945964008	✓	Drywall
Gypsum Wallboard - Painted	10.20	kg/m³	0.25	2.90%	663.0350786	1.423882604	✓	Drywall
Clean Wood				1.40%	320.0859			
Untreated Dimen. Lumber	500.00	kg/m³	0.25	0.90%	205.7695071	21.66150006	✓	Dimensional Lumber
Untreated Eng. Wood	500.00	kg/m³	0.25	0.20%	45.72655714	4.81366668	✓	Dimensional Lumber
Wood Pallets/Crates/Spools	500.00	kg/m³	0.25	0.30%	68.58983571	7.22050002	✓	Dimensional Lumber
Metal				2.80%	640.1718			
Appliances	7,850.00	kg/m³	0.25	0.00%	0	0		
Composite Metal (wires)	8,940.00	kg/m³	0.25	0.10%	22.86327857	43.03418012	✓	Copper Wires
Ferrous Scrap	7,850.00	kg/m³	0.25	0.60%	137.1796714	226.7237006	✓	Steel Cans
Non-Ferrous Metal *	5,826.00	kg/m³	0.25	2.10%	480.12885	588.9328636	✓	(Copper Wire * 0.5) + (Aluminum Ingot * 0.5)
MSW				0.00%	0			
Bulky Items (inc. mattresses)				0.00%	0	0		
E-Waste				0.00%	0	0		
MMSW				0.00%	0	0		
Other Paper				0.00%	0	0		
R/C and Other Glass				0.00%	0	0		
Tires				0.00%	0	0		
Uncoated OCC - Recyclable				0.00%	0	0		
Plastics				0.20%	45.72655714			
Durable Plastic Items				0.00%	0	0		
Film Plastic (Comm./Indus.)				0.00%	0	0		
HDPE Buckets				0.00%	0	0		
Plastic Furniture				0.00%	0	0		
R/C and Other Plastic	3,000.00	kg/m³	0.25	0.20%	45.72655714	28.88200008	✓	Mixex Plastics
Note:								
* The average densities of aluminium and copper were used as a generalization for non-ferrous metal densities								

Table 5

2023 Reuse sales logs by material type and origin location

Origin Breakdown							% Relationship Between Quantity & Revenue by Origin	% Relationship Between Weight & Revenue by Origin
Origin Location:	Count	Count % Makeup	Total Weight (tons)	Total Weight % Makeup	Total Revenue (\$)	Total Revenue % Makeup		
Court House-Donation	15.00	0.32	0.72	3.51	103.50	0.66	0.34	-2.85
Concrete Pile	4.00	0.09	1.25	6.14	193.00	1.23	1.14	-4.91
Donation	704.00	15.06	0.00	0.00	0.00	0.00	-15.06	0.00
Demolition Pile	88.00	1.88	2.06	10.09	692.66	4.41	2.53	-5.68
Dynamic Homes-Donation	89.00	1.90	0.79	3.85	868.57	5.53	3.63	1.68
Department of Corrections-Donation	12.00	0.26	0.21	1.03	26.50	0.17	-0.09	-0.86
Highway Department-Donation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metal Pile	431.00	9.22	2.60	12.73	2108.28	13.43	4.21	0.70
Material Recovery Facility	32.00	0.68	0.07	0.37	145.75	0.93	0.24	0.56
Osage Transfer Station	31.00	0.66	0.21	1.03	139.00	0.89	0.22	-0.14
Pay Station	1.00	0.02	0.00	0.02	4.00	0.03	0.00	0.01
Sentence To Serve-Donation	2.00	0.04	0.01	0.02	4.00	0.03	-0.02	0.00
Tire Pile	2.00	0.04	0.01	0.03	9.00	0.06	0.01	0.03
D.L. Transfer Station	3263.00	69.81	12.48	61.18	11400.97	72.64	2.83	11.46

Table 6

2023 Reuse Program sales logs by material type and origin location.

Material Type Breakdown							Relationship Between Item Quantity & Revenue	Relationship Between Item Weight & Revenue
Material:	Count (item quantity)	Count % Makeup	Total Weight (tons)	Total Weight % Makeup	Total Revenue (\$)	Total Revenue % Makeup		
Paper	230.00	7.32	0.34	2.36	470.75	3.63	-3.69	1.27
Plastic	901.00	28.67	2.53	17.67	3124.65	24.09	-4.58	6.42
Electronics	128.00	4.07	0.48	3.38	599.50	4.62	0.55	1.25
Metal	1595.00	50.75	8.31	58.12	7483.26	57.69	6.94	-0.43
Glass	255.00	8.11	1.01	7.08	857.21	6.61	-1.50	-0.47
Carpet	3.00	0.10	0.65	4.56	154.50	1.19	1.10	-3.37
Brick/Stone/Ceramics	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lumber	30.00	0.95	0.94	6.57	261.25	2.01	1.06	-4.55

Vinyl Windows	1.00	0.03	0.04	0.28	20.00	0.15	0.12	-0.13
Wood (non-lumber)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7

Demo Waste Percentage Expenses Contribution Factors

Demo Waste Attribution Conversion Factors	
Category	Percentage
Wasteworks	12.00%
Labor	12.00%
Telephone	50.00%
Postage	50.00%
Conference dues	50.00%
advertising	50.00%
utilities	50.00%
feul oil/ natural gas/ ect.	50.00%
auditing	50.00%
janitorial services	50.00%
compactor related equipment repairs	100.00%
balance machine repairs	15.00%
meal & travel expenses	12.00%
office rent	12.00%
insurance	12.00%
sales tax* (*per uncompacted CU. YD.)	\$0.60
misc charges	12.00%
office supplies	12.00%
uniform allowance	12.00%
gas & fuel	20.00%
equipment	12.00%

Table 8a*WARM CO₂E and SSC from landfill maximization.*

Maximizing Landfilling Processing Production and End-of-Life CO ₂ E							
Version 16 of the Waste Reduction Model							
Material	GHG Emissions from Production (MTCO ₂ E)	End-of-Life Impacts (MTCO ₂ E)					Production + End-of-Life Impact (MTCO ₂ E)
		GHG Emissions from Recycling	GHG Emissions from Landfilling	GHG Emissions from Combustion	GHG Emissions from Composting	GHG Emissions from Anaerobic Digestion	
Yard Trimmings	NA	NA	-1.82	-	-	-	-1.82
PP	10.11	-	0.13	-	NA	NA	10.24
Mixed Plastics	54.11	-	0.58	-	NA	NA	54.69
Aluminum Ingot	2,201.81	-	5.96	-	NA	NA	2,207.77
Steel Cans	686.4	-	4.59	-	NA	NA	690.99
Copper Wire	2,268.66	-	6.84	-	NA	NA	2,275.49
Glass	6.59	-	0.25	-	NA	NA	6.84
Asphalt Concrete	112.74	-	20.58	NA	NA	NA	133.32
Asphalt Shingles	0.11	-	0.01	-	NA	NA	0.12
Clay Bricks	226.87	NA	17.22	NA	NA	NA	244.09
Concrete*	4645.956	-	156.84	NA	NA	NA	4802.796
Dimensional Lumber	76.28	-	-33.34	-	NA	NA	42.95
Drywall	0.37	-	-0.1	NA	NA	NA	0.27
Medium-density Fiberboard	4.84	NA	-1.36	-	NA	NA	3.48
Wood Flooring	306.87	-	-64.11	-	NA	NA	242.76
Mixed Recyclables	NA	-	0.39	-	NA	NA	0.39
							-
TOTALS	10601.716		112.66				10714.376
COST	\$2,014,326.04		\$21,405.40				\$2,035,731.44

Note:

* CO₂E from Concrete production was not calculated by WARM. The International Energy Agency's estimation of 0.6 t of CO₂ per tonne of cement produced was used to estimate emissions.

<https://www.iea.org/energy-system/industry/cement>

Table 8b*WARM CO₂E and SSC from recycling maximization.*

Maximizing Recycle Processing Production and End-of-Life CO ₂ E							
Version 16 of the Waste Reduction Model							
Material	GHG Emissions from Production (MTCO ₂ E)	End-of-Life Impacts (MTCO ₂ E)					Change (Alt - Base) MTCO ₂ E
		GHG Emissions from Recycling	GHG Emissions from Landfilling	GHG Emissions from Combustion	GHG Emissions from Composting	GHG Emissions from Anaerobic Digestion	
Yard Trimmings	NA	NA	-1.82	-	-	-	-1.82
PP	10.11	-5.26	-	-	NA	NA	-5.39
Mixed Plastics	54.11	-26.73	-	-	NA	NA	-27.31
Aluminum Ingot	2,201.81	-2,121.24	-	-	NA	NA	-80.57
Steel Cans	686.4	-415.37	-	-	NA	NA	-271.02
Copper Wire	2,268.66	-1,514.98	-	-	NA	NA	-753.67
Glass	6.59	-3.43	-	-	NA	NA	-3.16
Asphalt Concrete	112.74	-82.25	-	NA	NA	NA	-30.49
Asphalt Shingles	0.11	-0.05	-	-	NA	NA	-0.06
Clay Bricks	226.87	NA	17.22	NA	NA	NA	244.09
Concrete*	4645.956	-61.88	-	NA	NA	NA	-4584.076
Dimensional Lumber	76.28	-59.91	-	-	NA	NA	-16.37
Drywall	0.37	0.04	-	NA	NA	NA	-0.42
Medium-density Fiberboard	4.84	NA	-1.36	-	NA	NA	-3.48
Wood Flooring	306.87	-274.94	-	-	NA	NA	-31.93
Mixed Recyclables	NA	-32.36	-	-	NA	NA	-32.36
Totals	10601.716	-4598.36	14.04				6017.386
COST	\$2,014,326.04	-\$873,688.40	\$2,667.60				\$1,143,303.34

Table 8c*WARM CO2E and SSC from Becker County's 2023 REUSE Data*

Material	Baseline Generation of Material (Tons)	GHG Emissions from Landfilling	GHG Emissions from Source Reduction
Mixed Paper (general)	0.48	0.04	-2.92
PVC	2.53	0.05	-4.87
Mixed Plastics	2.53	0.05	-4.74
Mixed Electronics	1.01	0.02	-21
Mixed Metals	8.31	0.17	-30.32
Glass	1.42	0.03	-0.75
Carpet	0.02	0	-0.07
Dimensional Lumber	0.02	-0.02	-0.04
Total	16.32	0.34	-64.72
Total Cost		\$64.60	-\$12,296.80

Table 9*Secondary method of obtaining the expected total operating life of the landfill*

Report Year	Expected Remaining Operating life (YRS.)	Expected Year of Closure
2007	28.19	2035.19
2008	31.53	2039.53
2009	21.52	2030.52
2010	28.23	2038.23
2011	28.93	2039.93
2012	37.25	2049.25
2013	26.75	2,039.75
2014	26.68	2040.68
2015		
2016		
2017		
2018	19.57	2037.57
2019	19.57	2038.57
2020	10.7	2030.7
2021	11	2032
2022	11	2033
Average Expected Clousre Yr.		2037.301538



Figure 1. *Location of Becker County Landfill in Minnesota.*

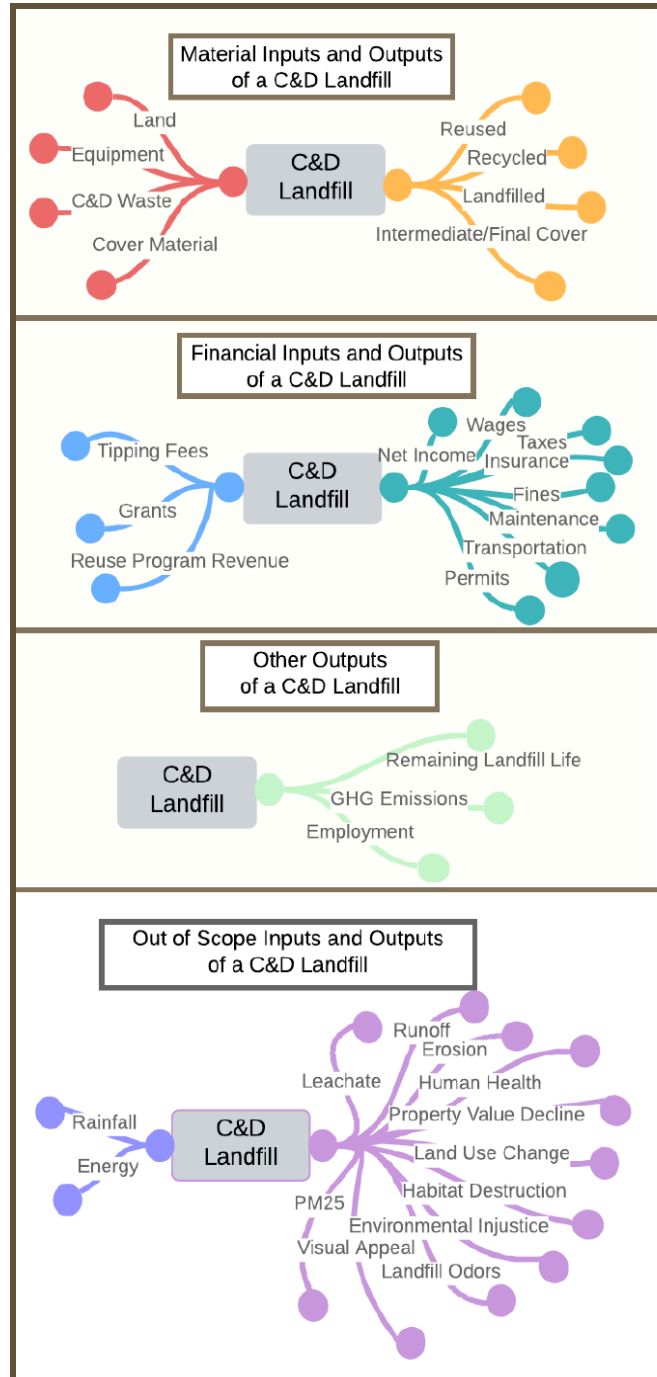


Figure 2. *Inputs and outputs of a C&D landfill, including materials, finances, and others.*

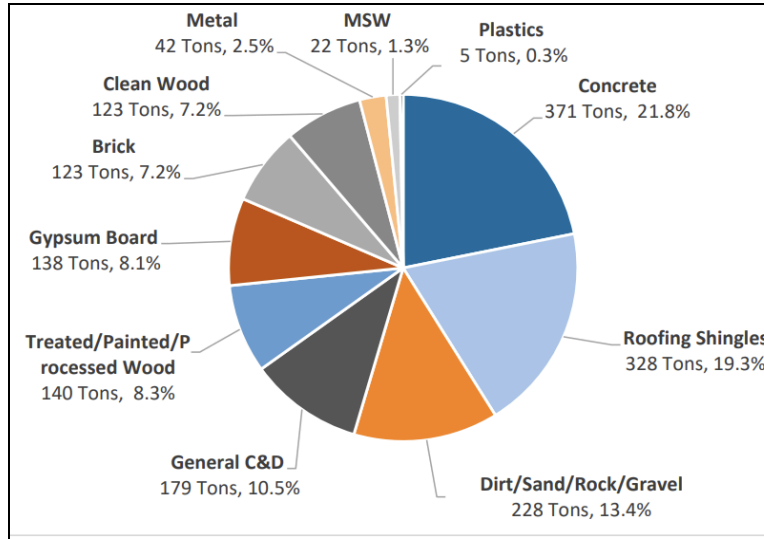


Figure 3. *The aggregate statewide C&D waste composition from 2019.*

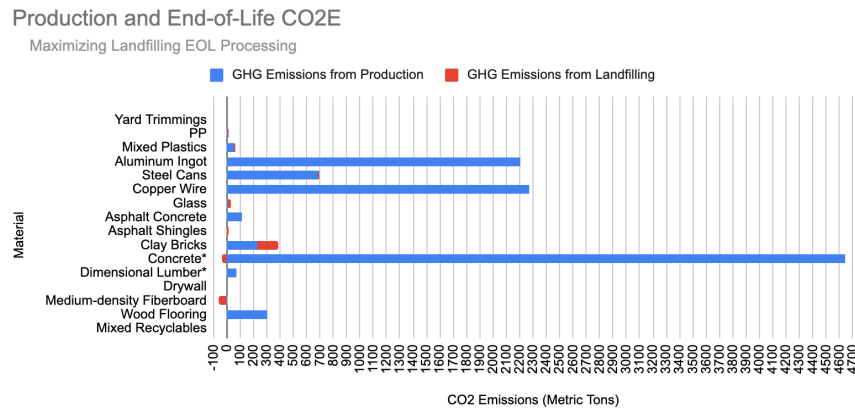


Figure 5. *Bar graph showing emissions from the production of waste materials and at the landfilling EOL.*

Production and End-of-Life CO2E

Maximizing Recycling EOL Processing

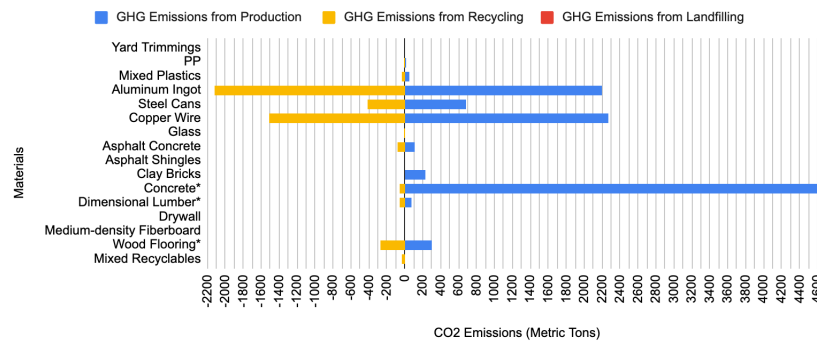


Figure 6. Bar graph showing emissions from the production of waste materials and at the recycling EOL.

REUSE Program's 2023 CO2E

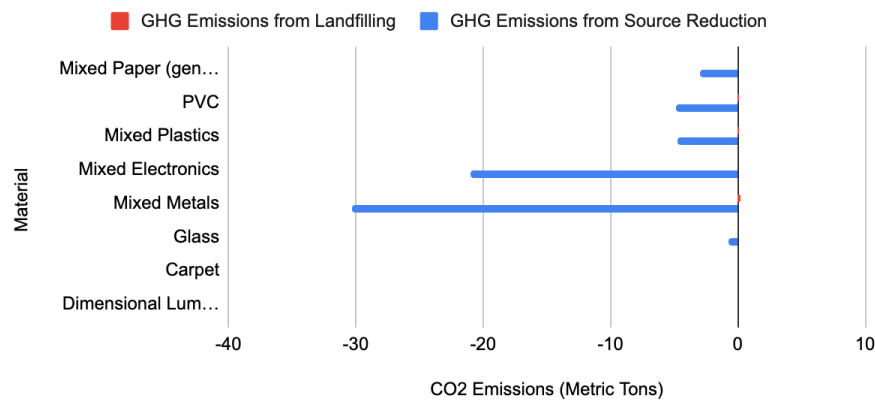


Figure 7. Net emissions of Becker County's Reuse program.

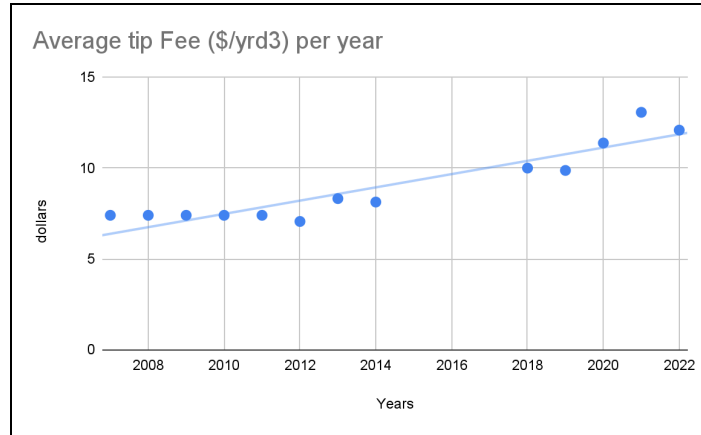


Figure 6. *Tip fee per year.*

Note. This graph shows how the tip fee has changed each year, which is important information to know so we can compare what we calculate the true cost to be against the tipping cost.

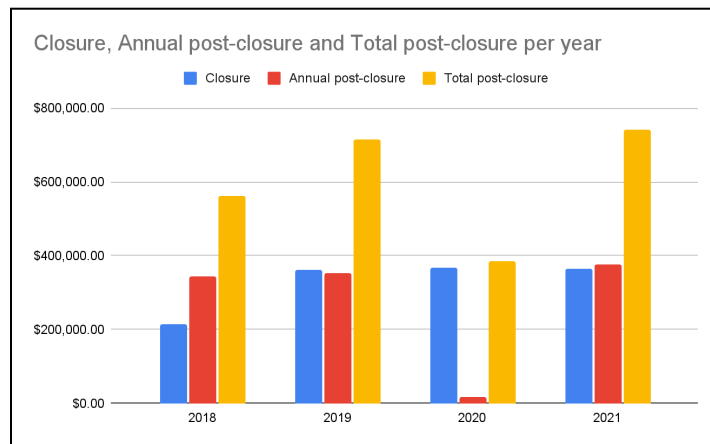


Figure 7. *Closure cost per year.*

Note. When the landfill closes, the county will need to continue to spend money on maintenance for many years. This is accounted for in the total post closure cost per year. Including this cost in our final analysis will be essential for getting the most accurate result.

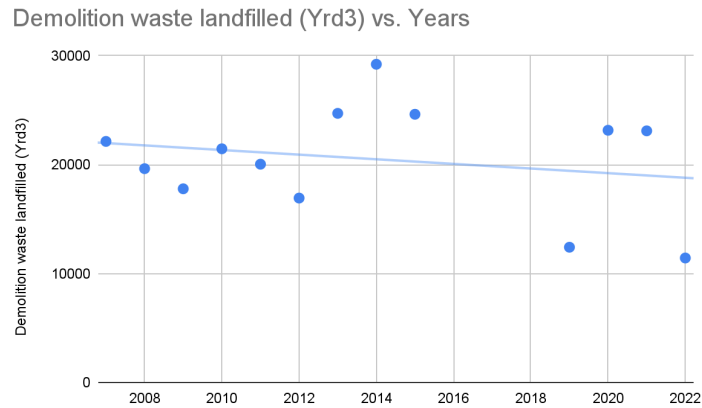


Figure 8. *Demolition waste landfilled per year.*

Note. This shows how much demolition landfill in yards cubed has been added to the landfill each year. Using this the total landfill can be determined and used in our analysis.

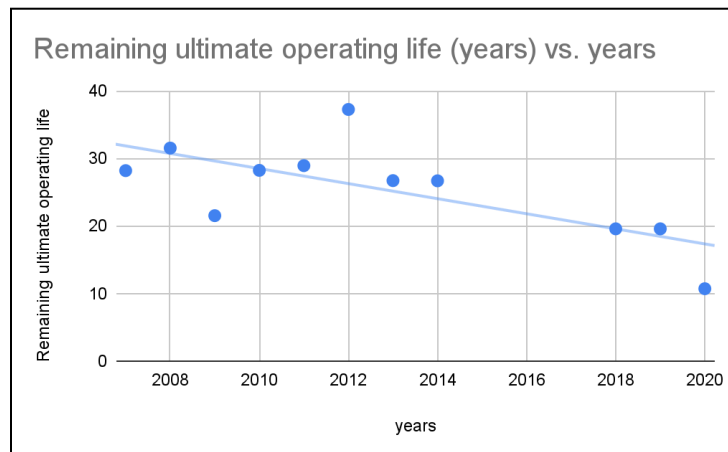
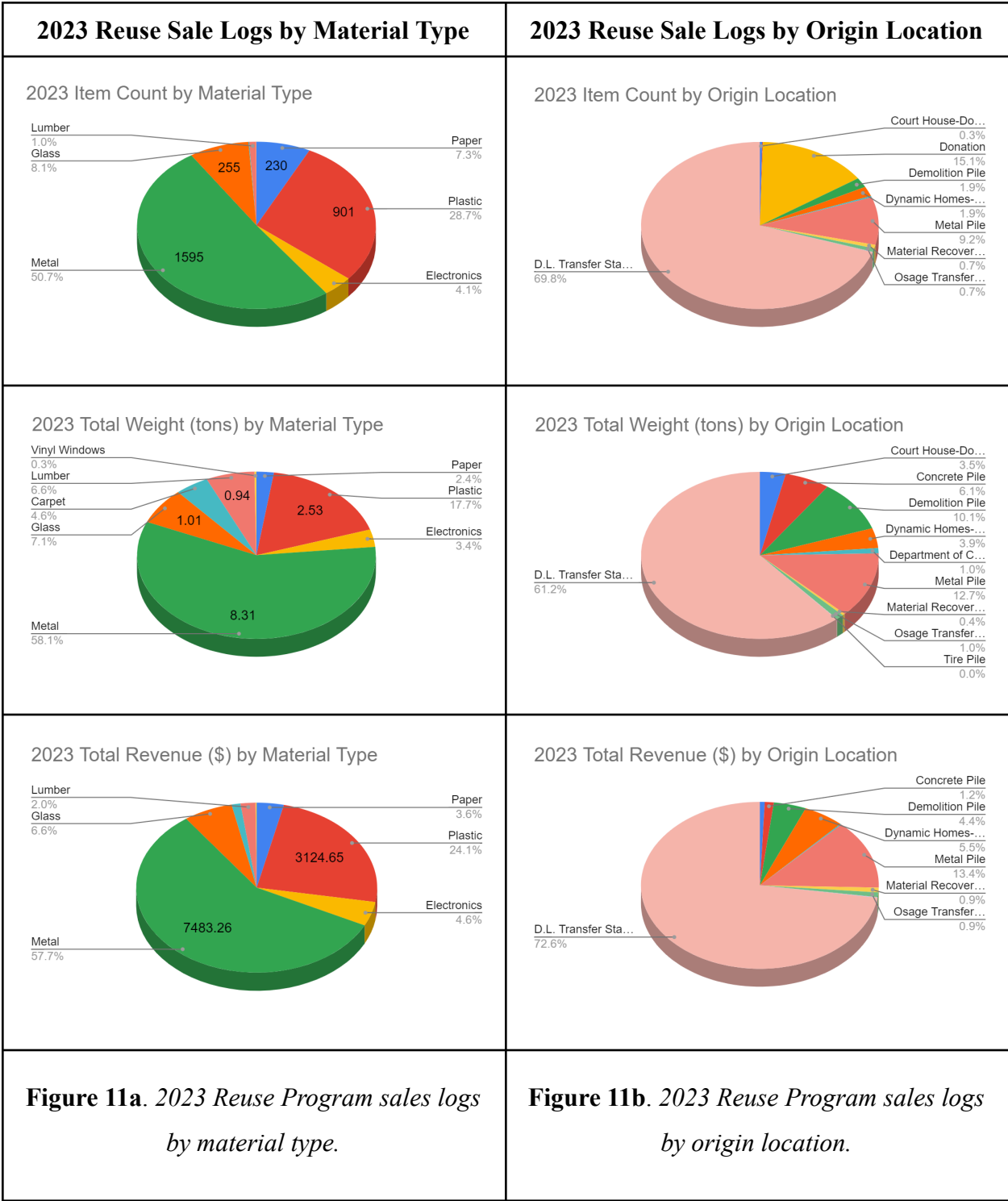


Figure 9. *Landfill lifetime per year.*

Note. Each year the estimated length that the landfill can operate changes, but determining a definitive closure date is essential with this project. This graph can be used to determine that date.



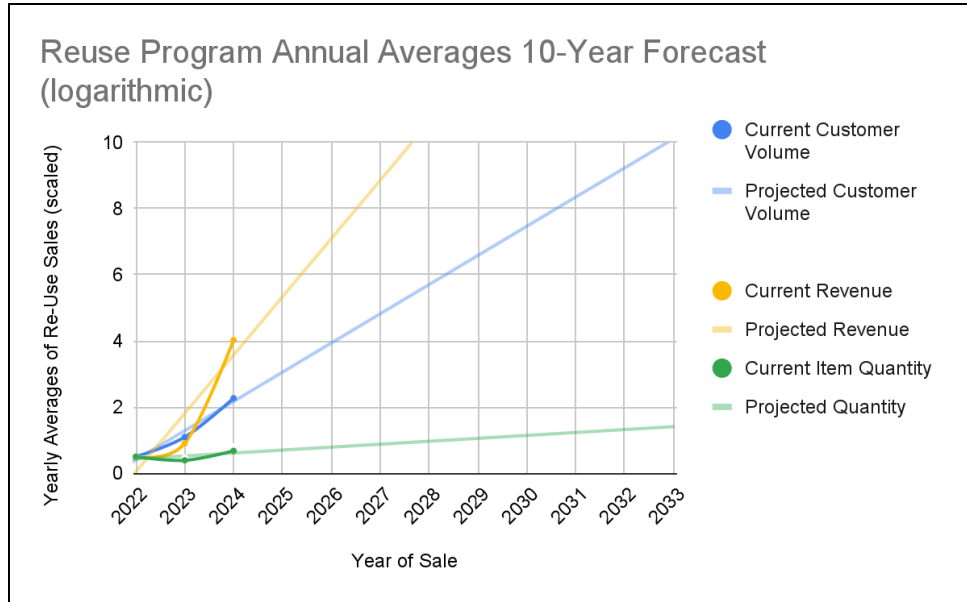


Figure 12a. *The yearly average of Reuse Program sales projected logarithmically until 2033.*

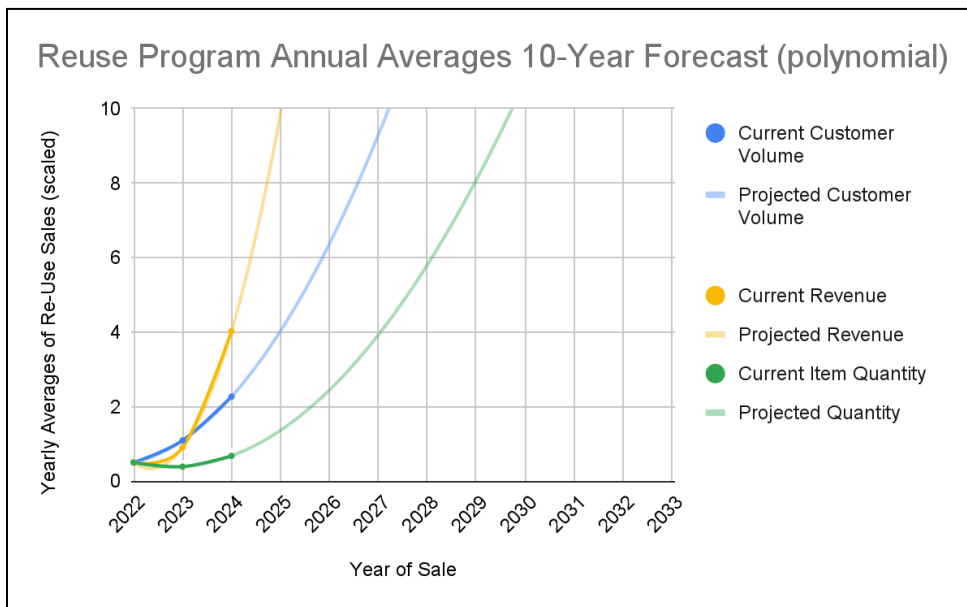


Figure 12b. *The yearly average of Reuse Program sales projected polynomially until 2033.*

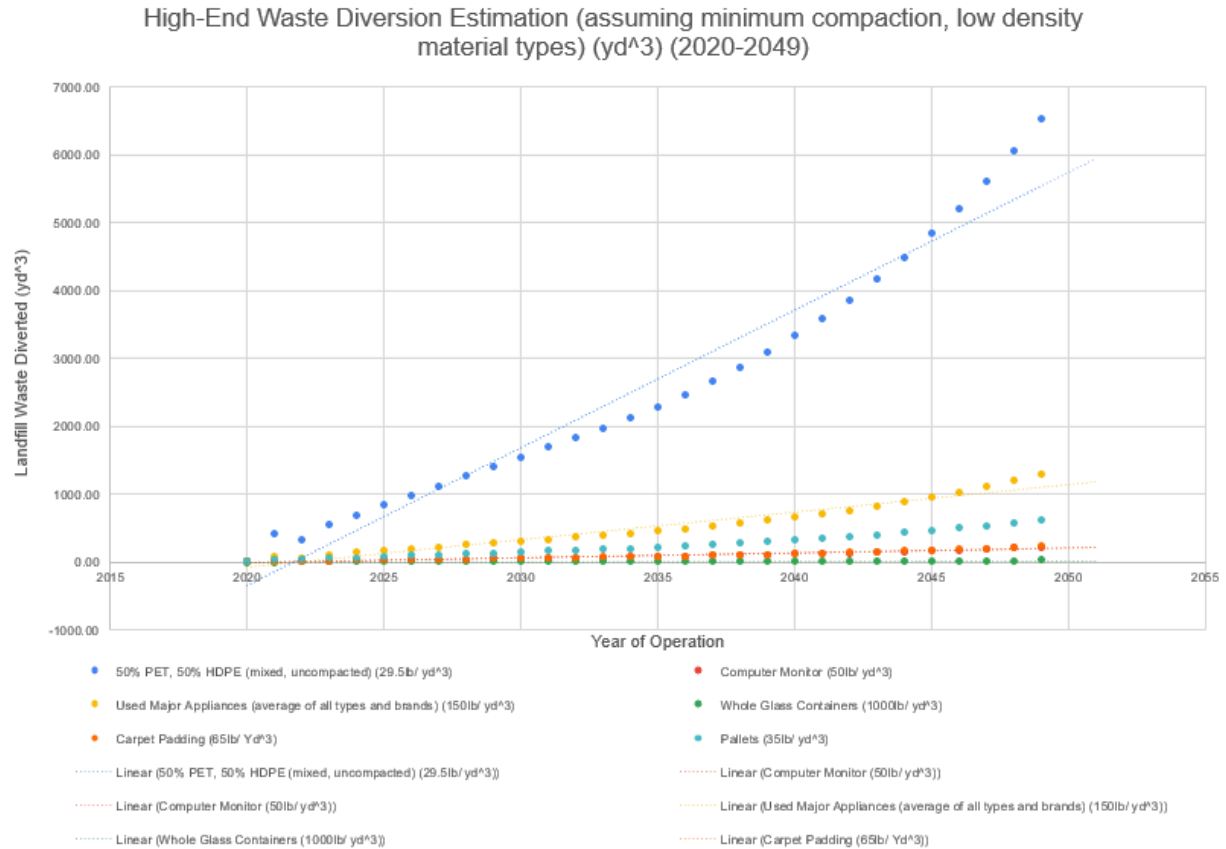


Figure 13a. A linear high-end 2020 to 2049 projection for waste volume in cubic yards given current growth in waste diverted via Becker County's Reuse Program. This predicts a total reduction of 106,547 yd³ by 2049.

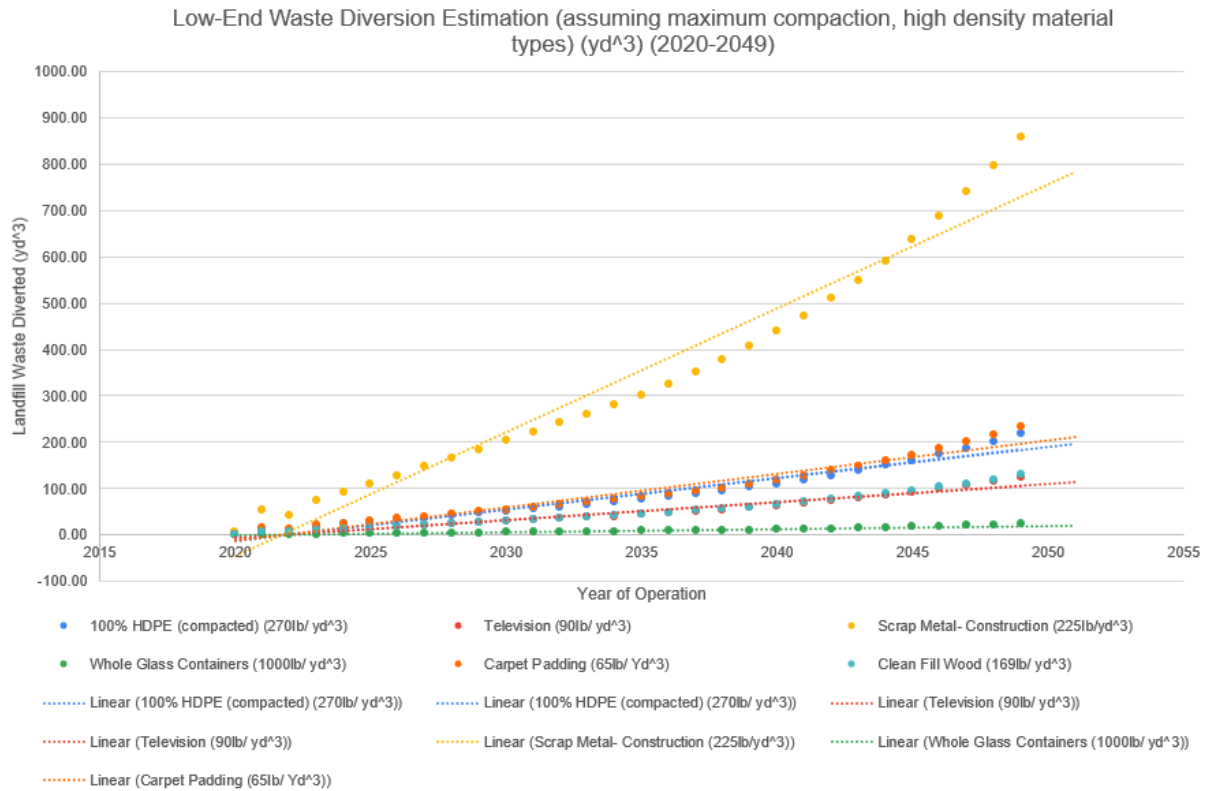


Figure 13b. *A linear low-end 2020-2049 projection for waste volume in cubic yards given current growth in waste diverted via Becker County's Reuse Program. This predicts a total reduction of 18,947.32 yd³ by 2049.*