



Life Cycle Assessment of the Management of Four Solid Waste Streams in Iowa

SMM – Vision for Iowa

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1.0 PROJECT OVERVIEW

In 2019, the Iowa Department of Natural Resources (DNR) launched an effort to develop a long-term vision for a more sustainable approach to solid waste management across the state. Since then, a series of research projects and strategic stakeholder-driven planning efforts have explored ways to improve how Iowa manages waste and resources.

During the stakeholder led strategic planning process, it was identified that Iowa needs a better understanding of the environmental impacts associated with solid waste management practices of consumer goods. One key takeaway from these discussions was the need for a better understanding of the environmental impacts of everyday products and waste materials. Knowing where these impacts occur can help guide decisions by manufacturers, consumers, and waste managers, leading to more sustainable product design, transportation, recycling, and disposal practices.

To better understand these impacts, the DNR commissioned a Life Cycle Assessment (LCA) study. The following four waste material categories were selected for the study based on stakeholder input and previous Sustainable Materials Management (SMM) initiatives:



Aluminum Containers



Food Waste



Plastic Film Waste



Textiles and Leather Waste

Figure 1 shows the total tons of the four selected materials disposed of in Iowa.

Figure 1. Waste Materials Selected for Iowa Life Cycle Assessment Study



Together, these materials accounted for approximately 32 percent of all residential and industrial, commercial, and institutional (ICI) waste disposed of in Iowa (2022 Iowa Statewide Material Characterization Study). The goal of this LCA study is to support policy evaluation and planning by providing a transparent, science-based assessment of the potential environmental impacts associated with current and alternative waste management practices across the state. This study also presents an opportunity for alternative material management practices with less environmental impacts than current practices.

1.1 WHAT IS A LIFE CYCLE ASSESSMENT

A life cycle assessment (LCA) is a systematic and comprehensive method used for assessing a range of cumulative environmental impacts across the full life cycle of a product: from material acquisition to manufacturing, use, and final management (i.e., landfilling, recycling, composting, etc.) (Figure 2). The impacts are quantified at each step in a product's life cycle to identify where the greatest environmental impact occurs and where improvements can be made.

Figure 2. Life Cycle Assessment Snapshot

WHAT IS A LIFE CYCLE ASSESSMENT?

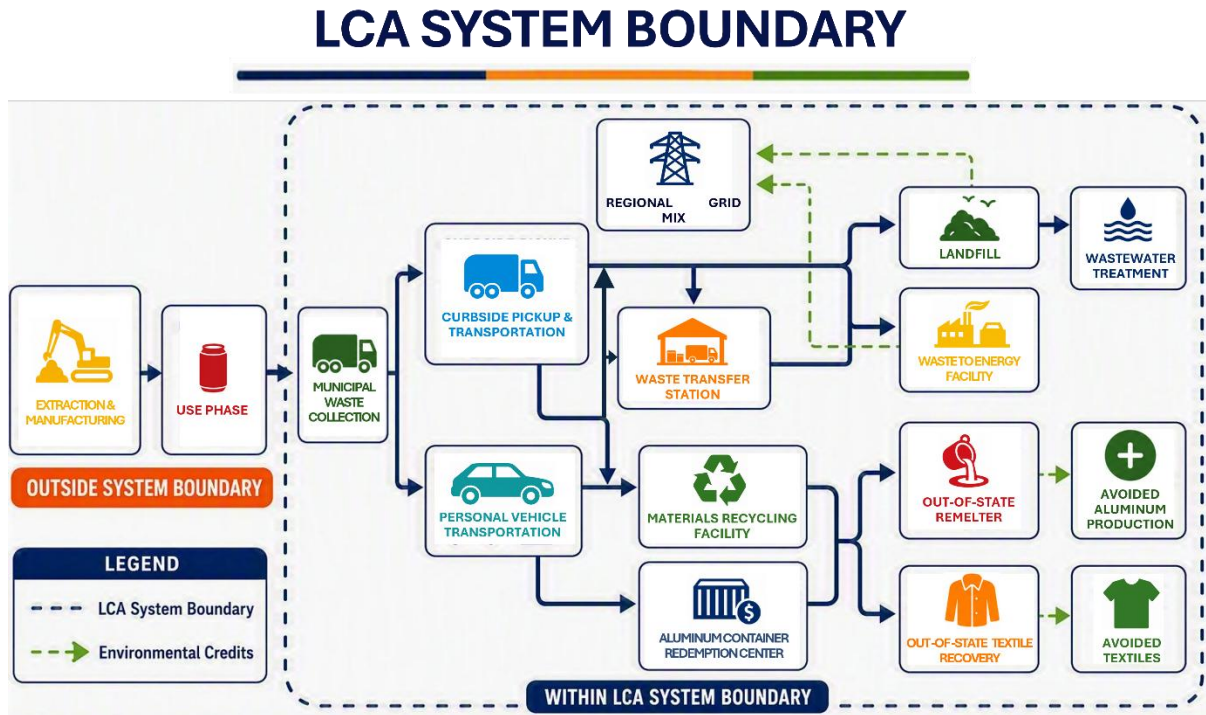


1.2 PROJECT SCOPE

This study investigates the flows of waste materials based on Iowa's existing solid waste management system and evaluates the associated baseline environmental impacts. It also explores alternative scenarios to measure the environmental impacts of potentially modified waste management practices and compares them against current practice impacts. These comparisons will help inform future solid waste management system changes and policy level decisions in the State of Iowa.

The system boundary of the LCA starts at the point of waste generation and extends through the entire downstream solid waste management system, including actions related to collection, transportation, processing, and waste disposal. Environmental impacts are measured in each step and aggregated throughout the waste material management process. Figure 3 shows the LCA boundary map where the focus of this study is on the end-of-life stage with most processes occurring within the State of Iowa. In addition, the environmental impacts associated with product manufacturing until the waste collection phase were modelled separately to provide context for better comprehending the results in end-of-life waste management processes.

Figure 3. Life Cycle Assessment Boundary



The performed LCA's measured environmental impacts in the following three major different categories, such as:



Carbon Dioxide Equivalent Emissions

- Reported as carbon dioxide (CO₂) equivalent accounted for gas¹ emissions in collection and processing, end-of-life disposal, as well as emission credits for recycling and energy recovery.



Energy Use

- Cumulative energy demand (CED) measures the direct and indirect energy inputs used to create, transport, and manage products after consumption, including both renewable and non-renewable energy sources.



Water Quality Impact – Eutrophication

- Reported as Nitrogen (N) equivalent representing nutrient loads entering water bodies that degrade water quality and cause algal blooms and fish kills. Water quality impacts are not limited to the final disposal stage; rather, it reflects the cumulative effects of nutrient discharges from multiple processes throughout the supply chain.

¹ Methodology Note – CO₂ equivalent emissions accounting: To compare all material management options on the same basis, gas emissions in this report are expressed as carbon dioxide equivalents (CO₂-eq). CO₂-eq is a common accounting unit used to compare the emissions impact of different gases, not a direct measurement of physical gas volume. For example, when food waste decomposes in a landfill without oxygen, it produces methane, a gas that has a much stronger air quality effect than carbon dioxide. Instead of reporting methane separately, its impact is converted into an equivalent amount of CO₂ using a standard conversion factor based on its air quality effect over 100 years. This approach provides a consistent way to compare total system emissions from different waste streams, such as food waste, plastics, metals, and textiles, on a common scale.

1.3 LIFE CYCLE ASSESSMENT METHODS

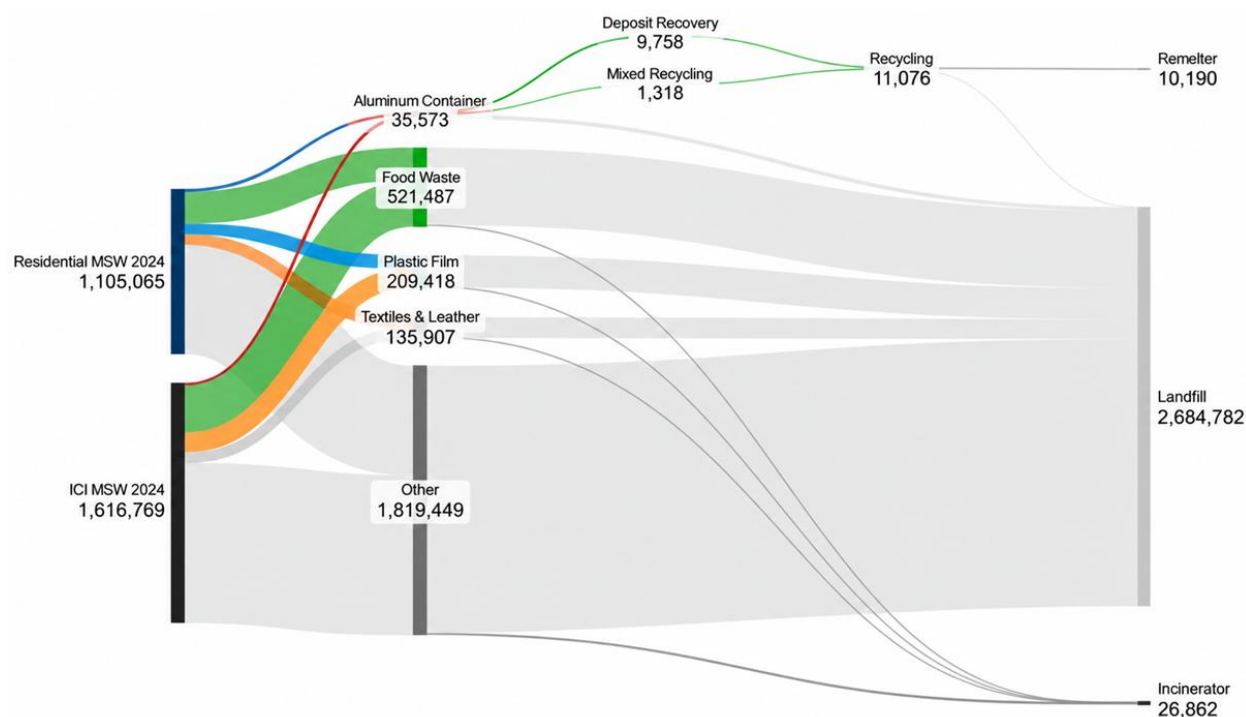
LCA's follow strict scientific protocol and systematic approaches as established in ISO 14040 and 14044 standards and use industry software and a peer-reviewed database to calculate environmental impacts. Environmental impacts were expressed in terms of one metric ton and state-wide flow quantities for each waste material from both residential and ICI sources in Iowa. CO₂ equivalent emissions, cumulative energy demand, and eutrophication were selected by DNR as the impact categories of interest. The tools listed below were used to develop the results.

- TRACI 2.1 was used to quantify emissions impacts (kg CO₂-eq) and Eutrophication (kg N-eq). TRACI (Tool for Reduction and Assessment of Chemical and Other Environmental Impacts) is a tool developed and maintained by the U.S. Environmental Protection Agency that translates inventory data from a product's life cycle into environmental impacts. TRACI uses regional data specifically from the United States.
- Cumulative Energy Demand (CED) was used to quantify total life cycle energy use, accounting for energy from both renewable and non-renewable energy resources. The CED impact is expressed in Megajoules (MJ) or Terajoules (TJ) oil equivalent.

The full LCA report, which describes the methodologies and presents the results in detail, has been critically reviewed in accordance with ISO protocols and approved by an independent third-party panel of LCA experts.

The LCA for each waste material utilized Iowa specific tonnages and available solid waste management practice inputs (Figure 4) to develop results that are uniquely relevant to Iowa's solid waste practices.

Figure 4. Sankey Diagram of Residential and ICI Municipal Solid Waste Flows



1.4 LIFE CYCLE ASSESSMENT BASELINE SCENARIOS

Below are the four categories' baseline scenarios selected for study by Iowa DNR.

Aluminum Containers

Aluminum containers include aluminum beverage containers subject to Iowa's container deposit law and those made from aluminum other than Iowa deposit containers; food containers made from aluminum and the thin aluminum foil sheeting used to cover and wrap food.

Iowans generate approximately 36,000 tons of aluminum waste each year from both residential and ICI sources. However, only about 31% (11,000 tons) of this material is recovered for recycling, while the remaining 69% (more than 25,000 tons) is disposed of in landfills.

For this study, the current (baseline) scenario 69% of aluminum containers are collected with municipal solid waste through curbside pickup or drop-off programs and ultimately sent to landfills. The remaining 31%, including deposit aluminum beverage containers, is recovered through Iowa's container deposit system or mixed recycling programs, processed at recycling facilities, and then transported to aluminum remelters outside Iowa to be recycled into new products.



Food Waste

Food waste includes materials resulting from the processing, storage, preparation, cooking, handling, and consumption of food. Food material in the original packaging was included but the mass of the packaging materials was excluded from the scope of this study.



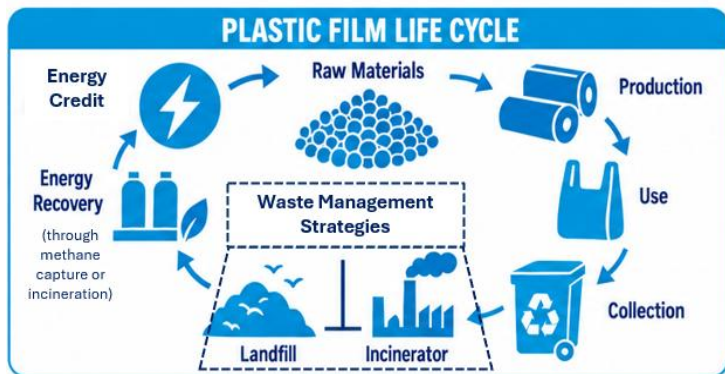
Food waste from both residential and ICI sectors makes up one of the largest portions of Iowa's waste stream, accounting for approximately 19% of all solid waste disposed of in the state, or about 520,000 tons per year.

For this study, nearly all food waste (about 99%) was modeled to be collected with municipal solid waste through curbside pickup or drop-off programs and transported to landfills. A small portion (about 1%) was modeled to be sent to the incineration facility. Other management methods, such as composting, anaerobic digestion, and other food waste diversion programs, currently handle less than 0.1% of Iowa's food waste. Because these management pathways represent such a small fraction of the total waste stream, they were below the study's cutoff threshold and were not included in the analysis.

Plastic Film Waste

Plastic film waste includes plastic shopping bags, garbage bags, food wrappers, and other types of plastic film, such as candy-bar wrappers, mailing pouches, commercial/ industrial film, etc.

In Iowa, plastic film from both residential and ICI sources is estimated to make up about 8% of the solid waste disposed of each year, totaling approximately 210,000 tons. For this study, nearly all plastic film waste (about 99%) was modeled to be collected with municipal solid waste through curbside pickup. A small portion (about 1%) was modeled to be transported to the incineration facility. Plastic film recycling was not included in the baseline model because it currently represents a very limited waste management pathway in Iowa compared to landfill disposal.



Textiles and Leather Waste

Textiles and leather waste include items that are composed of at least 50 percent natural or manmade textile and leather, such as yarn, thread, clothing, apparel, shop rags, blankets, pillows, shoes, stuffed toys, backpacks; includes leather items such as wallets, purses, belts, shoes, and scrap leather.



Textiles and leather waste from both residential and ICI sources is estimated to make up about 5 percent of the solid waste disposed of in Iowa per year, or about 136,000 tons. As with food waste, the majority of textiles and leather waste was modeled as collected within MSW (approximately 99%), via curbside pickup or center drop off, and disposed of in landfills, with a small portion (1%) transported to incineration. Textiles and leather recycling was not included in the baseline model as this data is not available.



2.0 BASELINE ENVIRONMENTAL IMPACTS

2.1 PRE-CONSUMPTION ENVIRONMENTAL IMPACTS

Across the four material categories evaluated in this study, the environmental impacts of representative products that occur before a product is used, including raw material extraction, manufacturing, and transportation to market (the "cradle-to-gate" stage), were found to be greater than the impacts that occur after the product is discarded (the "gate-to-grave" post-consumption stage). Environmental impacts in many product systems are unevenly distributed across life-cycle stages, with manufacturing dominating total impacts. This highlights an important opportunity for improvement: by recovering and recycling materials instead of producing new materials from virgin resources, significant environmental impacts can be avoided.

2.2 SUMMARY/COMPARISON – KEY TAKEAWAYS

Figures 5 and 6 summarize the modeled environmental impacts associated with the current Iowa waste management strategies for the four waste material categories. Each waste material is examined individually to present its environmental impacts across three impact categories and to provide insights into the performance and implications of the current waste management system.

Figure 5. Iowa Environmental Impacts of Current Waste Management Practices

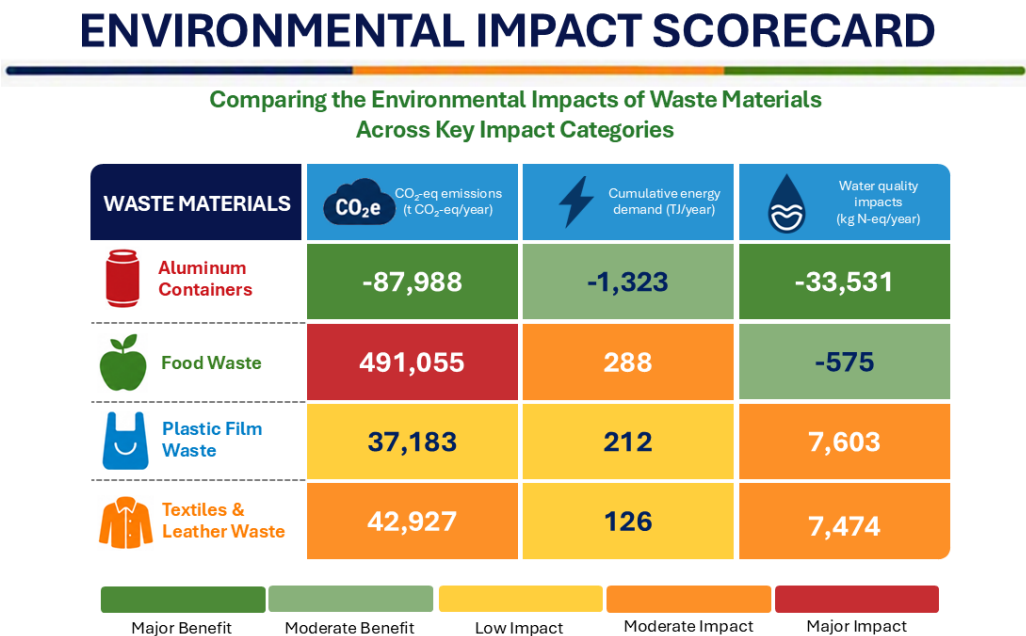
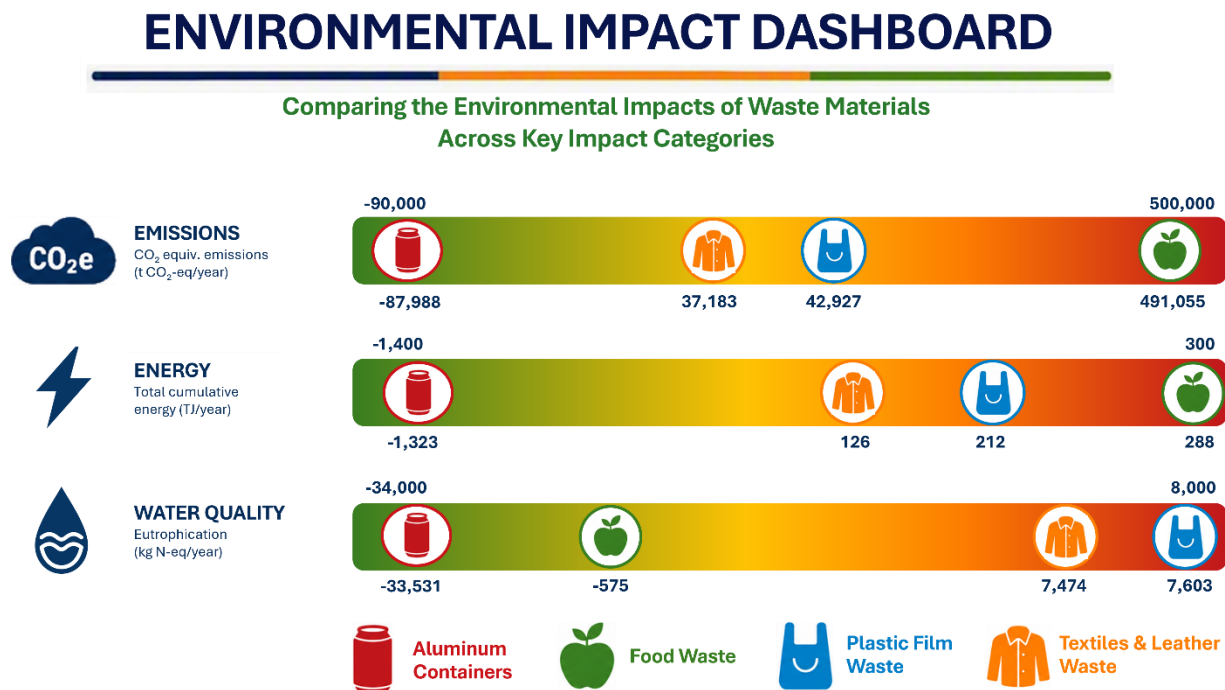


Figure 6. Baseline of Statewide Environmental Impacts



Figures 7 through 9 illustrate the environmental impacts of the current management practices into more relatable terms note below.

- CO₂ eq. emissions → equivalent CO₂ emissions from # of passenger vehicles driven in a year;
- Total cumulative energy demand → equivalent energy in # million gallons of gasoline;
- Water impacts – eutrophication → kilograms of nitrogen equivalent required to produce # bushels of corns.

Figure 7. Current Iowa Waste Management Practices - Emissions

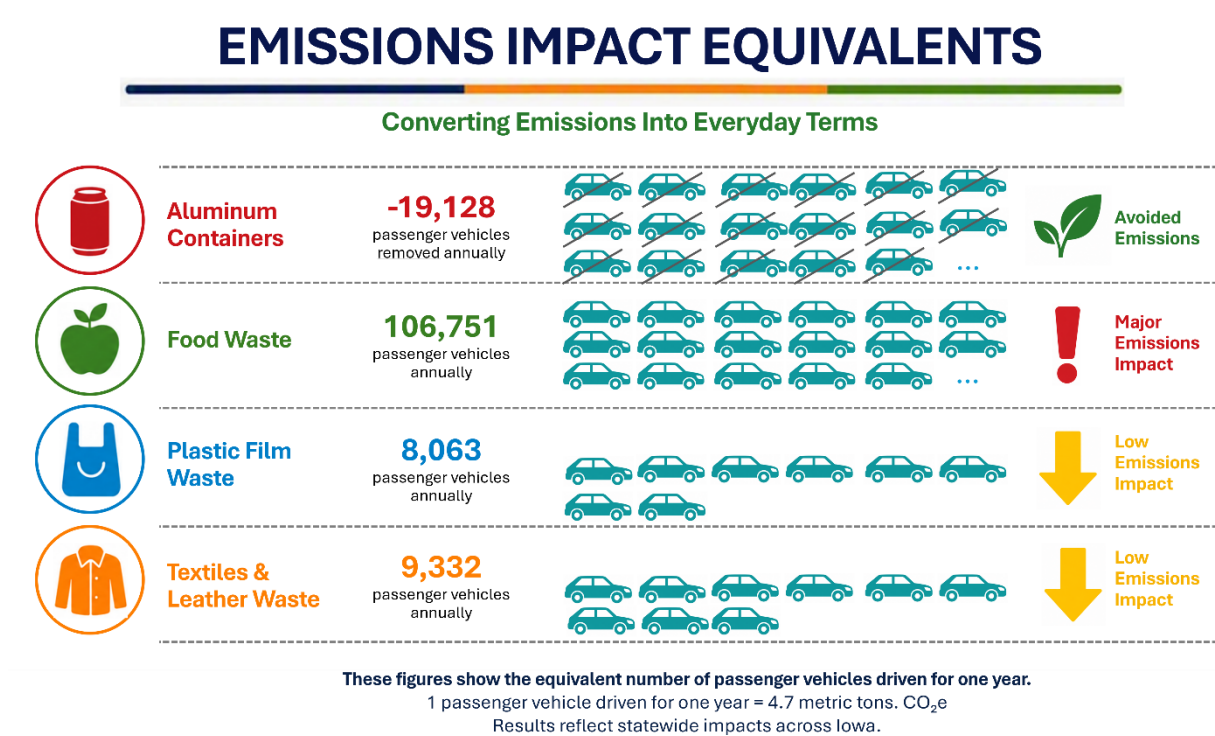


Figure 8. Current Iowa Waste Management Practices - Energy

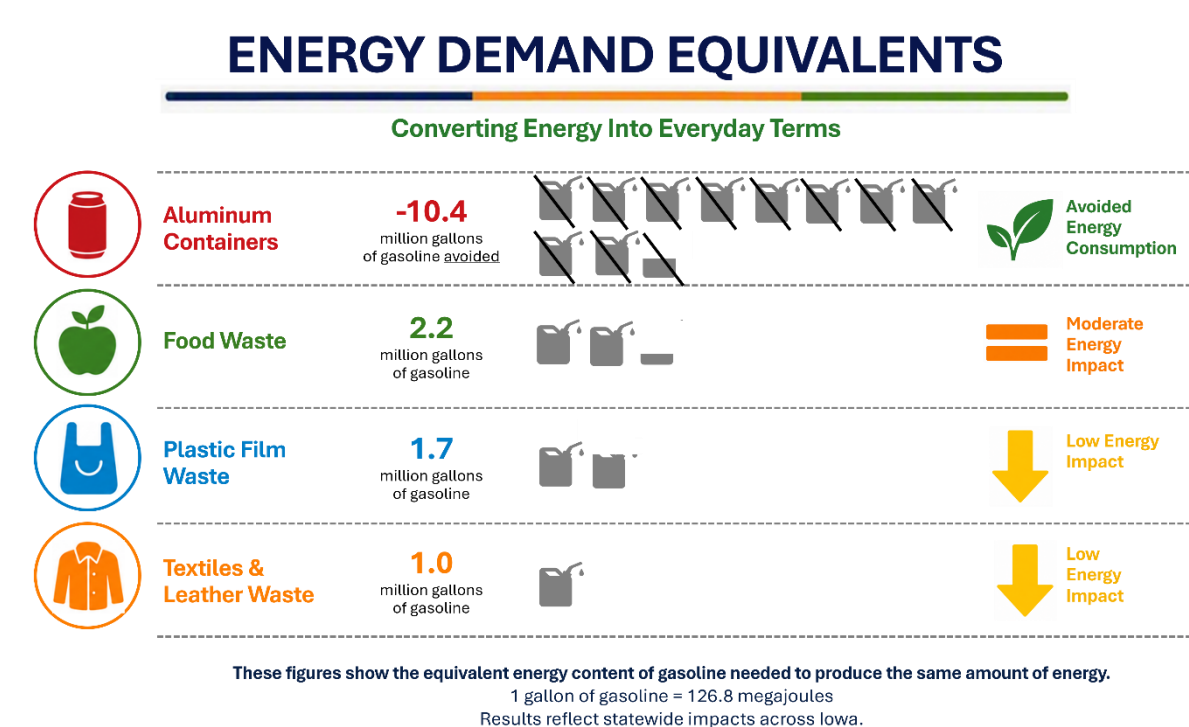
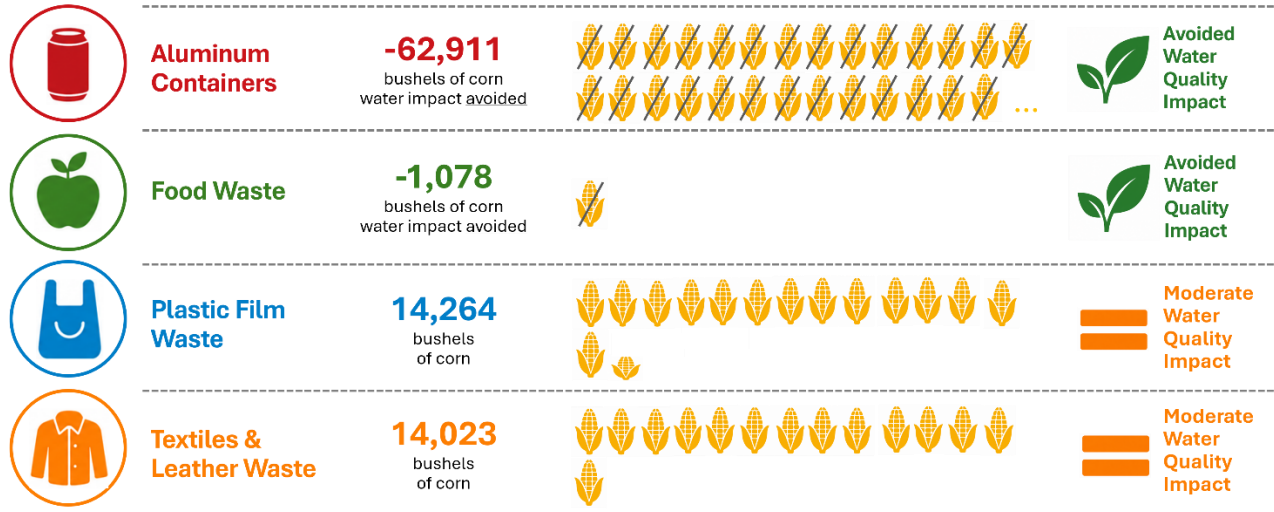


Figure 9. Current Iowa Waste Management Practices - Water Quality

WATER QUALITY EUTROPHICATION EQUIVALENTS

Converting Eutrophication Impact Into Everyday Terms



These figures translate eutrophication impacts into the equivalent nitrogen associated with producing bushels of corn.

1 bushel of corn = 0.533 kg nitrogen eq.

Results reflect statewide impacts across Iowa.

2.3 BASELINE ENVIRONMENTAL IMPACT KEY TAKEAWAYS

The following subsections present the key takeaways from the environmental baseline impact results for each of the four evaluated waste materials.



2.3.1 Aluminum Containers

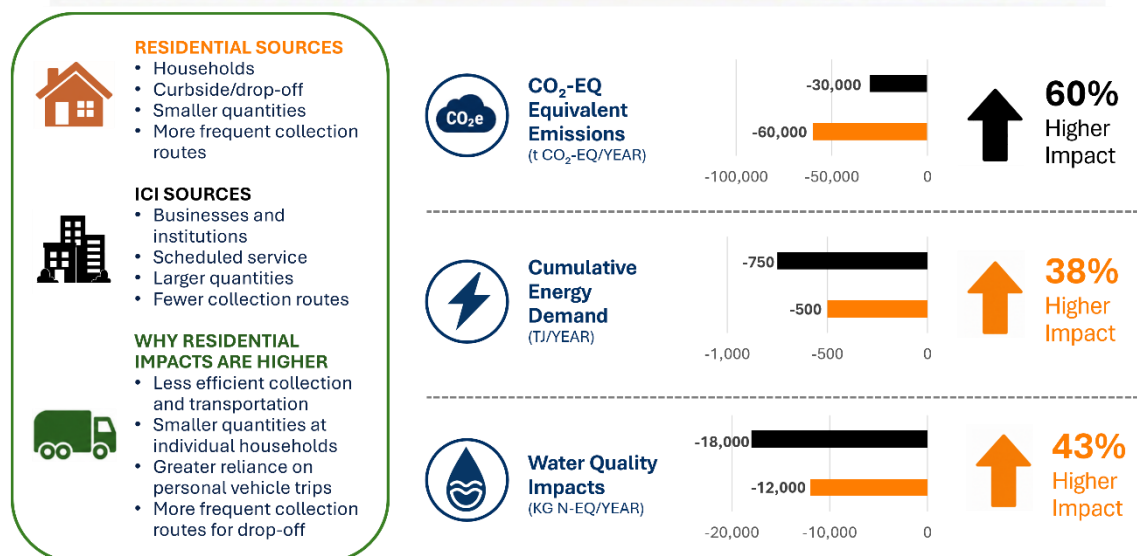
The first waste material assessed is aluminum containers, which recovery through recycling generate substantial environmental benefits across all three impact categories.

Key Takeaways:

- Residential waste management generally had higher environmental impacts than ICI waste management (Figure 10). Across most materials, CO₂ equivalent emissions and energy use per ton of waste were approximately 20% to 60% higher for residential waste. This difference is largely driven by less efficient collection and transportation logistics, smaller quantities of waste generated at individual households, and greater reliance on personal vehicle trips and more frequent collection routes for waste drop-off.
- Recycling deposit aluminum beverage containers provided the greatest environmental benefits among the waste management pathways evaluated (Figure 5). This approach resulted in the largest reductions in CO₂ equivalent emissions, energy use (CED), and nutrient pollution (eutrophication) impacts. These benefits are primarily due to the recovery of aluminum containers and the avoided need to produce new aluminum from raw materials, which is an energy-intensive process.
- Recycling aluminum through mixed recycling programs also delivered important environmental benefits, although the impacts were smaller than those achieved through the deposit-return system. Even so, recovering aluminum from the waste stream helps conserve resources and reduce the environmental burdens associated with manufacturing new aluminum products.

Figure 10. Environmental Impacts of Recycling Residential and ICI Generated Deposit Aluminum Beverage Containers

ALUMINUM CONTAINER WASTE MANAGEMENT



2.3.2 Food Waste

Food waste follows a fundamentally different management pathway, with environmental outcomes determined primarily by decomposition processes and landfill methane emissions rather than material substitution benefits.

Key Takeaways:

- Food waste sent to landfills is the largest source of CO₂ equivalent emissions among the four materials evaluated in this study. The primary reason is the release of fugitive methane when food waste breaks down without oxygen in a landfill. These findings highlight the importance of landfill methane capture and control systems, as reducing methane emissions could significantly lower Iowa's overall emissions.
- The emission and energy impacts associated with food waste management are driven largely by waste collection and landfill emissions. There are relatively few opportunities to offset these impacts through energy recovery or material reuse, resulting in a net consumption of energy throughout the waste management process.



2.3.3 Plastic Film Waste

As a non-biodegradable material, plastic film waste presents a different environmental profile with its impacts primarily driven by waste management operations.

Key Takeaways:

- Incinerating plastic film waste results in significantly higher CO₂ equivalent emissions per ton than landfilling. However, plastic incineration can also generate electricity, which provides energy recovery benefits and can offset impacts by reducing the need for power from other sources. As a result, incineration showed substantial energy credits and reduced nutrient pollution impacts in the analysis. Despite these benefits, given its limited capacity and absence of planned expansion, incineration is expected to play only a minor role in contributing to statewide environmental impacts relative to landfill disposal.
- Waste collection and disposal activities are the primary drivers of environmental impacts for plastic film waste. Transportation, collection operations, and landfill management account for most of the cumulative energy use and nutrient pollution impacts associated with the current waste management practices for plastic film waste.



2.3.4 Textiles and Leather Waste

Textiles and leather waste currently offer limited opportunities for impact reduction within the existing textiles waste management system.

Key Takeaways:

- Textiles and leather waste currently represent a net environmental burden across all impact categories evaluated. Due to the lack of available textile recycling data, the model focused on disposed textiles which presents no opportunities to recover value or offset environmental impacts through energy generation. While some energy can be recovered through waste-to-energy processes, the benefits are not large enough to compensate for the gross environmental impacts associated with disposal. Expanding textile and leather recycling and reuse programs could significantly reduce the environmental impacts associated with managing these materials.
- Waste collection and disposal activities are the primary contributors to environmental impacts for textiles and leather waste. Transportation, collection, and landfill emissions account for most of the cumulative energy demand and nutrient pollution impacts associated with the current management system.

2.4 BASELINE ANALYSIS IMPLICATIONS

Collectively, the findings across all four material categories highlight several common factors that influence environmental performance and point to opportunities for improving Iowa's waste management system.

- Material recovery rates and recycling efficiency have a major influence on environmental outcomes. Recovering more materials for recycling can significantly reduce CO₂ equivalent emissions while also delivering energy savings by replacing the need to manufacture products from virgin raw materials.
- Fugitive methane emissions from landfills are the largest contributor to overall CO₂ equivalent impacts. As a result, efforts to reduce or capture fugitive methane emissions offer some of the greatest opportunities for lowering the CO₂ emissions from Iowa's waste management system.
- Total energy demand is strongly affected by aluminum recycling rates, assumptions about electricity generation and grid displacement, and fuel requirement. Improvements in any of these areas can have a meaningful impact on overall energy consumption.
- Factors such as collection route efficiency, transportation distances, vehicle fuel use, and the number of trips made by residents to drop off materials can significantly influence both energy use and eutrophication impacts.
- The overall environmental burden of Iowa's waste management system is heavily influenced by the types and quantities of materials being managed. Because some materials generate much larger impacts than others, the statewide results for CO₂ equivalent emissions, energy demand, and eutrophication impacts are largely driven by how waste materials are distributed across the waste stream.



3.0 ALTERNATIVE SCENARIOS

Once the baseline environmental impacts for the four waste materials were established, the DNR selected three alternative scenarios for further analysis. These scenarios were designed to evaluate how changes in waste management practices could affect environmental impacts compared to current conditions. The comparison of alternatives to the baseline scenario provides valuable insights that can help guide consumer choices, support future policy and program development, and inform investments in waste management infrastructure across Iowa.

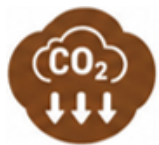
The three alternative scenarios selected for comparison to the established baseline include the following:



Increased Aluminum Container Recovery Rate (from 42% to 64%)



Centralize Residential Textile Collection for Out of State Recycling Rate (15% Diversion, 100% virgin materials that can be substituted with recycled materials, 20% Recycling & Processing Loss)

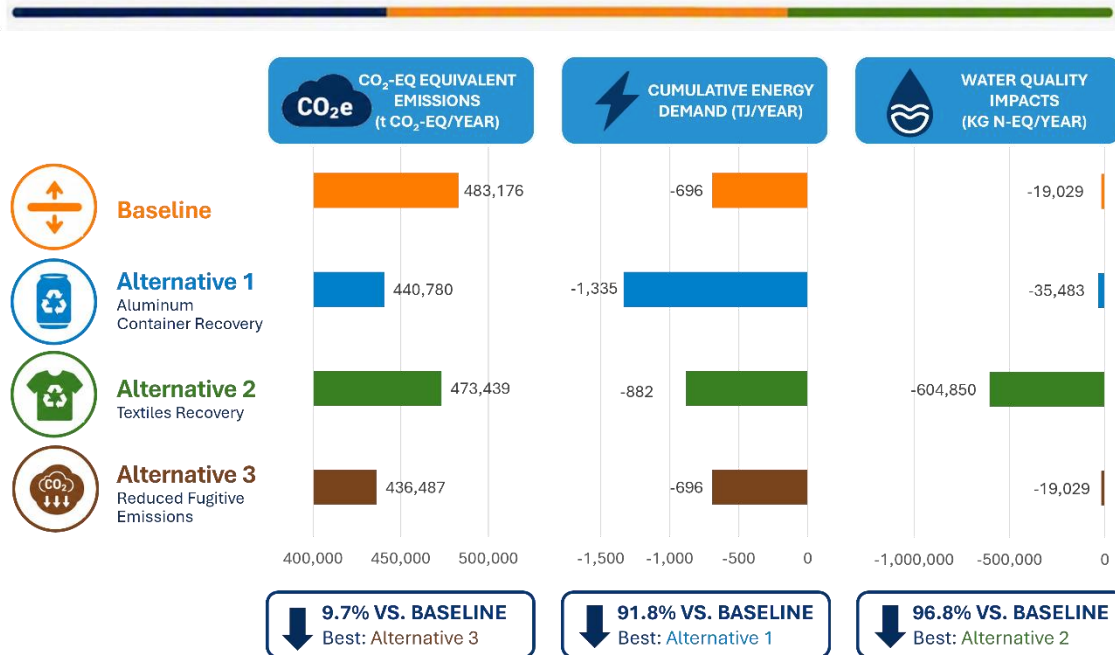


Reduction of 10% of Landfill Fugitive Methane Emissions

Figure 11 summarizes the modeled environmental impacts associated with alternative waste management strategies for the four waste material categories. The baseline represents the total environmental impacts of current waste management practices for the three evaluated materials.

Figure 11. Alternative Waste Management Practices and Environmental Impacts Compared to Current Practices

COMPARING WASTE MANAGEMENT SCENARIOS



Figures 12 through 14 illustrate the environmental impacts into more relatable terms comparing the baseline to the alternative waste management practices.

Figure 12. Baseline and Alternative Iowa Waste Management Practices - Emissions

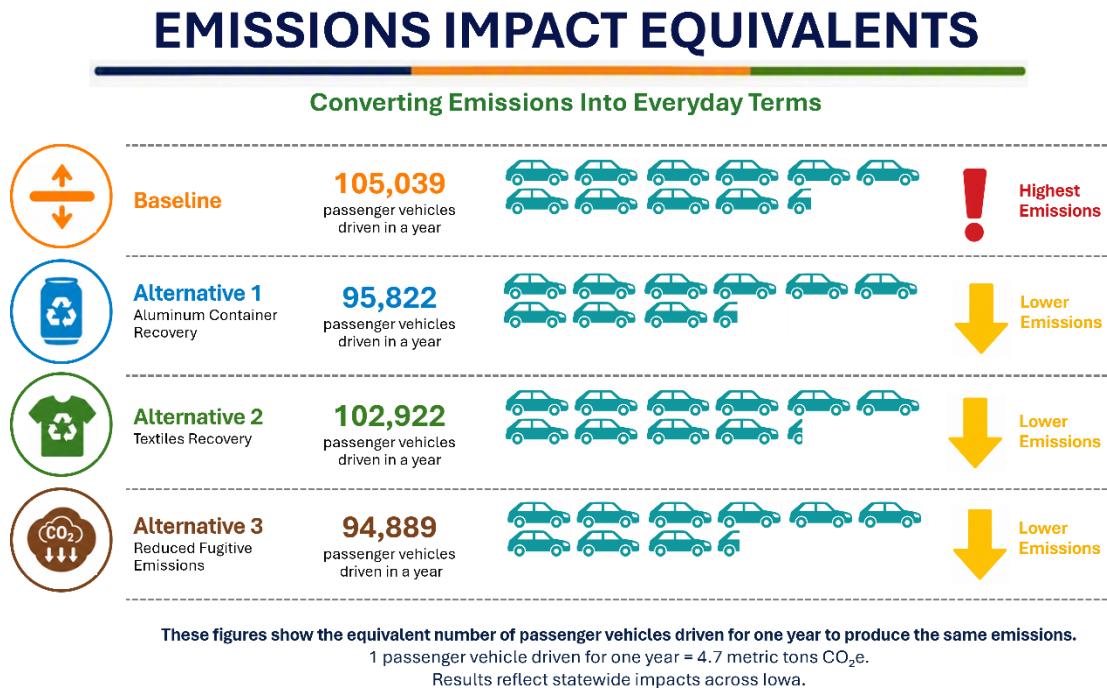


Figure 13. Baseline and Alternative Iowa Waste Management Practices - Energy

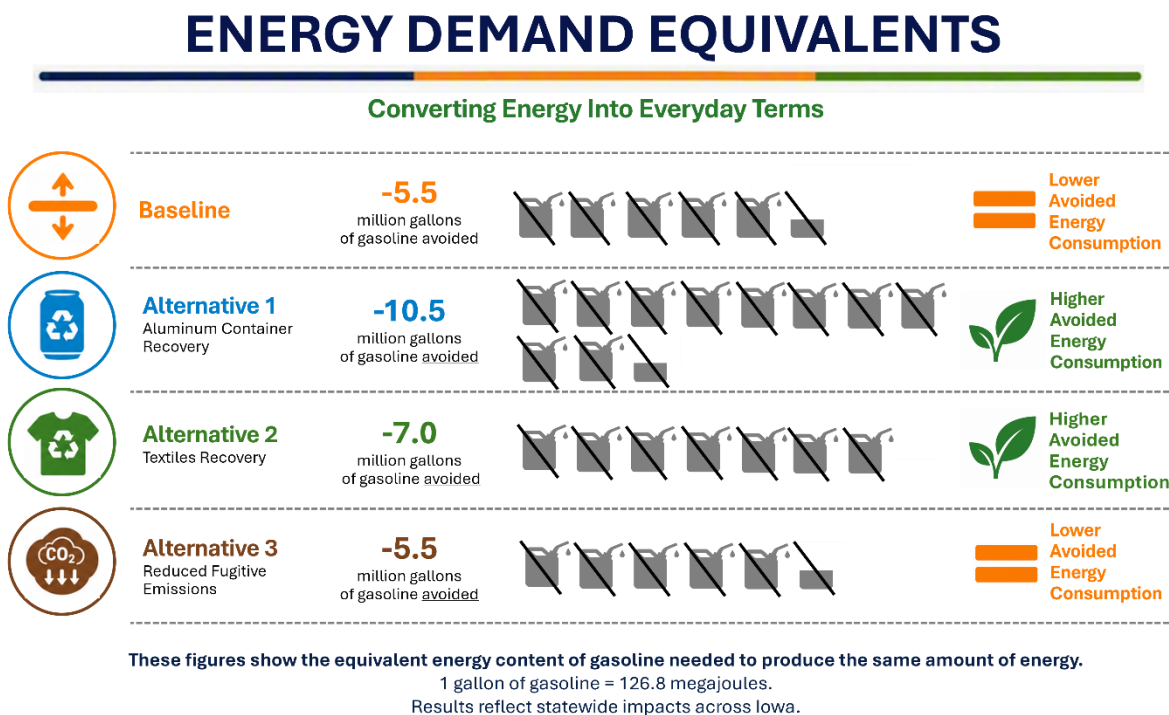
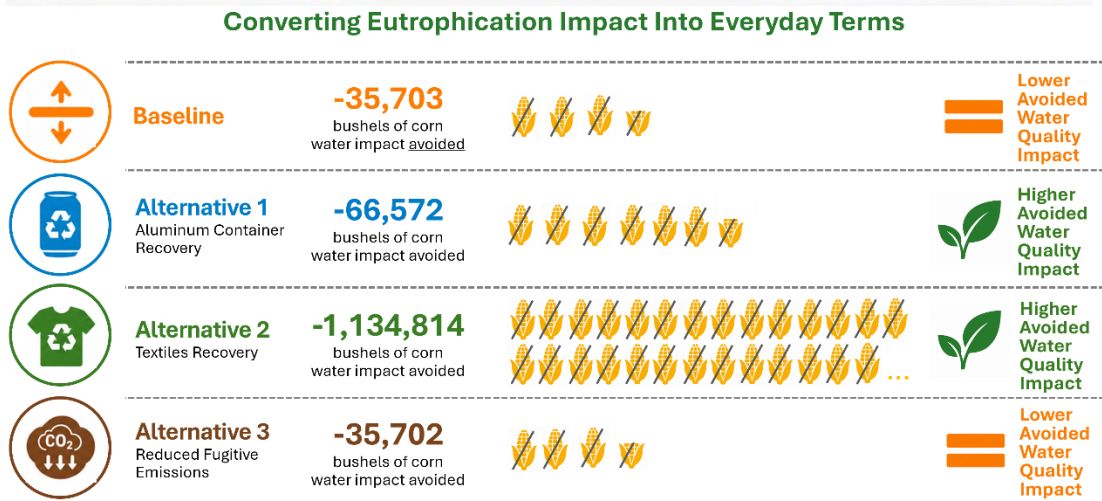


Figure 14. Baseline and Alternative Iowa Waste Management Practices – Water Quality

WATER QUALITY EUTROPHICATION EQUIVALENTS



These figures translate eutrophication impacts into the equivalent nitrogen associated with producing bushels of corn.

1 bushel of corn = 0.533 kg nitrogen eq.

Results reflect statewide impacts across Iowa.



3.1 INCREASED ALUMINUM DEPOSIT CONTAINER RECOVERY

The objective of this alternative scenario is to measure the potential environmental impact should Iowa increase aluminum deposit container recovery from 42 percent (2022 Iowa Statewide Material Characterization Study and 2022 Recovery Rate Report for Beverage Deposit Beverage Containers) to 64 percent, which is the 2024 average among states with deposit programs (Container Recycling Institute, 2025). This alternative scenario assumes that an additional 5,200 tons of deposit aluminum beverage containers are diverted from disposal for recovery through existing curbside collection, drop-off locations, and redemption center programs.

Key Takeaways:

- The magnitude of environmental benefits scales proportionally with additional recovery volume of deposit aluminum beverage containers. Because aluminum recycling yields the largest net energy savings, with one eighth gross CO₂ equivalent emissions of new aluminum container production, improvements in recovery rates translate directly into larger environmental benefits.



3.2 CENTRALIZED RESIDENTIAL TEXTILE RECYCLING

The objective of this alternative scenario is to measure the potential environmental impact should Iowa divert 15 percent of residential textile waste from disposal to a centralized in-state processor, and then to out of state mechanical recycling facilities. The national level recycling rate for textiles is 14.7 percent (EPA 2018 Fact Sheet).

This scenario evaluates the potential environmental benefits of establishing a textile recycling program in Iowa. Under this scenario, textiles would be collected at existing landfills and transfer stations, consolidated, and transported to a processing facility within the state. At the facility, non-textile components such as fasteners and disruptors would be removed, and the remaining materials would be sorted into cotton and polyester fractions. The recovered cotton and polyester would then be shipped to specialized textile recycling facilities outside Iowa for mechanical recycling. The recycled fibers would be used to replace virgin textile materials in the production of new products, reducing the need for raw material extraction and manufacturing. Any materials that cannot be recycled, along with processing losses, would continue to be disposed of in landfills.

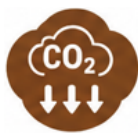
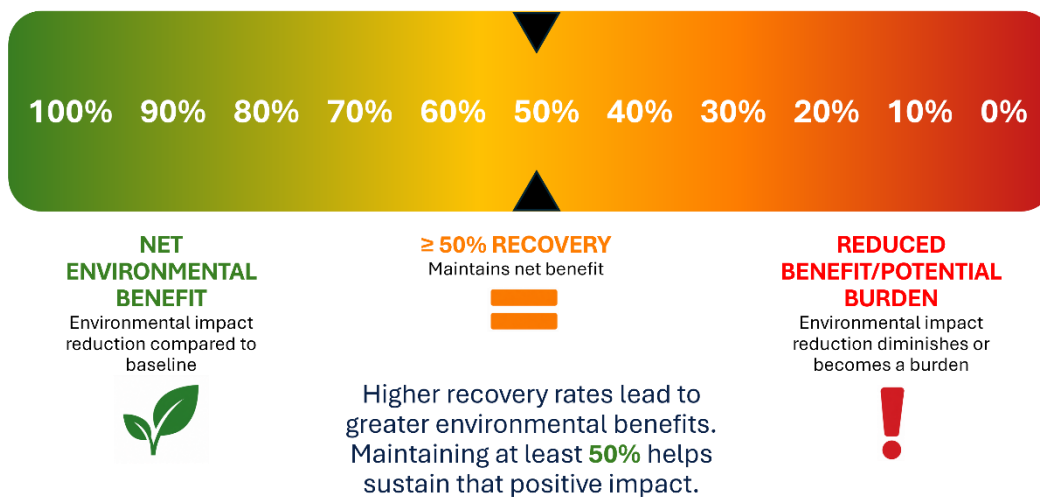
Since the environmental benefits of textile recycling depend heavily on how much material is successfully recovered and reused, the study evaluated different assumptions for material losses during the recycling process and the extent to which recycled fibers can replace virgin cotton and polyester and explored their effects on the environmental benefits when diverting textiles from landfill disposal.

Key Takeaways:

- The environmental benefits of textile recycling depend largely on how much material can be successfully recovered (Figure 15). The analysis found that at least 50% of the collected textiles must be converted into marketable recycled products to maintain net benefits for CO₂ equivalent emissions. Lower recovery rates can significantly reduce the overall environmental advantages of recycling textiles.
- Environmental benefits are also sensitive to the ability of recycled fibers to replace virgin materials. The environmental benefits of textile recycling come largely from avoiding the production of new cotton and polyester fibers. As the substitution rate decreases, these avoided production benefits decline, reducing the overall environmental gains from recycling.
- Transportation logistics play an important role in overall environmental performance. In this scenario, recycled textiles are transported an average of 1,140 miles to out-of-state recycling facilities. These long transportation distances contribute substantially to the environmental impacts of the recycling system, highlighting the potential value of developing more local or regional textile recycling infrastructure.

Figure 15. Effect of Textile Recycling Recovery Rate on Emissions

HOW RECOVERY RATES AFFECT EMISSIONS



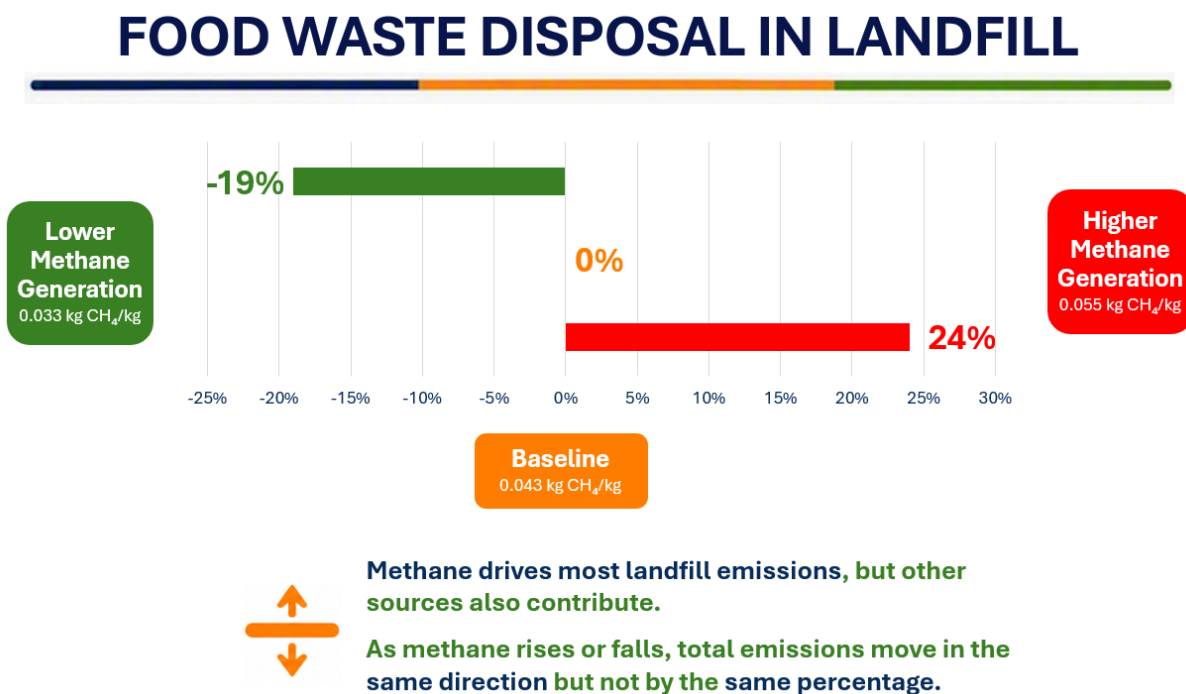
3.3 REDUCTION OF LANDFILL FUGITIVE METHANE EMISSIONS

This alternative scenario measures the potential environmental impact should Iowa's landfills reduce the fugitive methane emissions by 10 percent by increasing the efficiency of existing landfill gas (LFG) collection and beneficial LFG use systems, improving daily cover, and enhancing compaction operations. This scenario does not assume the construction of new landfill gas collection infrastructure at facilities that do not already have these systems in place. Instead, it focuses on operational improvements at existing facilities to better capture and control methane that would otherwise be released into the atmosphere.

Key Takeaways:

- CO₂ equivalent emissions are sensitive to variation in the methane emission factor (Figure 16). Compared with the baseline case, which assumes 0.043 kg of methane per kg of degradable waste, CO₂ equivalent emissions from landfill disposal of degradable material increased by approximately 24% under the higher methane generation case (0.055 kg CH₄/kg degradable waste) and decreased by approximately 19% under the lower methane generation case (0.033 kg CH₄/kg degradable waste). Methane drives most landfill emissions, but not all of them. As a result, increases or decreases in methane emissions lead to total emissions moving in the same direction, but not by the same percentage.
- Reducing methane emissions provides a direct and measurable reduction in CO₂ equivalent emissions. As methane capture and control improve, the environmental benefits increase proportionally, making landfill methane reduction one of the most effective strategies for reducing the overall emissions of Iowa's waste management system.

Figure 16. Sensitivity of Landfill Emissions Associated with Food Waste Disposal





4.0 CONCLUSIONS

- Landfill methane emissions, particularly from food waste, are the largest contributor to the waste system's CO₂ equivalent impacts. Reducing fugitive methane emissions from landfills is one of the most effective strategies for lowering Iowa's overall emissions and can deliver substantial air quality benefits.
- Increasing aluminum recycling offers the greatest environmental benefit, reducing CO₂ equivalent emissions, energy demand, and eutrophication by avoiding production of virgin aluminum ingots.
- Textile recycling has significant potential to reduce environmental impacts, but benefits depend on achieving high material recovery rates and minimizing transportation-related impacts.
- Overall, expanding material recovery and recycling programs while improving landfill gas management represents the greatest opportunity to reduce CO₂ equivalent emissions, conserve resources, and improve the sustainability of Iowa's waste management system.

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