Chicago Waste Generation and Characterization Update 2010-2020

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AUTHOR CONTRIBUTIONS

Project planning, study design, and report preparation: Ai; data processing, modeling, and charts: Zheng; data analysis and interpretation: Ai and Zheng; review of peer region solid waste plans, literature on construction and demolition waste, e-waste, and textile wastes: Gendel and Ai; literature review on organic waste, glass, and plastics: Rundquist and Ai; bibliography management: Zheng.

DISCLAIMER

This report reflects the most accurate information at the best of authors' knowledge. This does not represent the opinions or statements from the City of Chicago, Delta Institute, or the University of Illinois at Chicago. When there is information discrepancy across data references, the information directly released from the City of Chicago or original citations should be used.

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EXECUTIVE SUMMARY

In partnership with the Delta Institute for a 2020 Chicago Waste Strategy Study, the team at the University of Illinois at Chicago (UIC) was tasked with developing a profile about Chicago waste generation and characterization. Because a full-scale waste audit was not feasible in 2020, the UIC team was directed to provide estimates for 2020 based on Chicago historical data, along with regional and national datasets. Material-specific trends, innovations, and consumer expenditures were to be identified and summarized as well.

During the five-week project period (1/25/2021-2/26/2021), the UIC team performed qualitative and quantitative analyses of national, regional, and City reported data, academic research, industry surveys and reports, and well-regarded industry magazines as well as major news outlets. Table ES-1 summarizes the key findings and recommendations. Here are a few highlights:

- In 2020, the City of Chicago generated an estimated amount of 4.13 million tons of waste from residences, institutional/ commercial/industrial (ICI) sectors; and building construction and demolition (C&D) activities. Overall, there is an increase in waste generation in the last decade. Yearly fluctuations of waste generation volume seem to respond to economic conditions.

- In normalized measures (per capita or per household), Chicagoans generate more waste at home than residents in peer cities or regions (e.g., New York City and California). There are potentials for source reduction from Chicago residences.

- After the Chicago Blue/Black Cart Program expanded from limited coverage to city-wide implementation, commodity volume collected per household for recycling decreased, which suggests the increases in recycling participation did not keep up with the City's recycling program expansion. The decreasing trend of recycling performance turned around in 2018, when the City launched community campaigns to boost residents' participation in recycling and to reduce contamination. Reported data demonstrate that community education programs matter.

- Pandemic conditions have changed not only the waste quantity but also composition and location. While the locations of waste generation have shifted towards residences, residents' lack of recycling information and options (e.g., food waste, masks, and packaging from online shopping) may have contributed to the increases in residential waste generation volume in 2020.

- Multi-family residential units in Chicago increased steadily in the last decade. Given many documented challenges of MF residential recycling nationwide (e.g., NYC Bureau of Waste Prevention, Reuse and Recycling, 2001), additional resources and educational programs may be needed to advance residential recycling goals in Chicago.

- About 522,510 tons of organic waste are estimated to be generated in Chicago every year, including 245,260 tons from single-family (SF) residential, 81,250 tons from MF residential, and 196,000 tons from ICI sectors. Implementing source separation of 75% of organic waste from SF homes would boost landfill diversion rate by 18.6%.

- Light-weighting material trends (e.g., glass and electronic products) discourage recycling when using the traditional approach of measuring material and waste management by weight (tonnage) only. Additional studies are needed to assess the impacts of light-weighting trends.

- The availability and quality of waste stream data vary by generation activity (sector) and by service provider, which presents great barriers to understand the overall waste stream in Chicago. For both planning and community education purposes, consistency, clarity, and transparency, as well as enforcement of waste data reporting are important.

Importantly, data interpretation of numerical results should note the context and limitations. The tonnage is not and should not be regarded as the single metric to measure waste performance or impacts, for multiple reasons (e.g., material light-weighting trend and varying life cycle impacts across material classes). For cross-region or time-series analysis, it is inappropriate to compare the waste volume estimates in this study to the national average or other regions' data in which municipal solid waste (MSW) is defined or measured differently. For example, the United States Environmental Protection Agency, the US EPA, excludes C&D waste from the national MSW estimates. In contrast, the 2010 Chicago Waste Characterization Study and 2010 Chicago Diversion Study present a broader scope of C&D waste estimates than this study. Due to data constraints, the C&D volume estimates in this study include building C&D waste only; other C&D waste (e.g., from road and bridge construction and maintenance activities) are excluded. In addition, pandemic years, such as 2020, can be outliers and may not be suitable as a benchmark for decennial planning.

Table ES-1: Key Findings and Recommendations (1 of 3)

Key Findings	Recommendations
In 2020, the City of Chicago generated an estimated amount of 4.13 million tons of waste from residences, institutional/ commercial/industrial (ICI) sectors; and building construction and demolition (C&D) activities. Overall, there is an increase in waste generation in the last decade. Yearly fluctuations of waste generation volume seem to respond to economic conditions.	• Caution should be given when interpreting data under pandemic conditions or using 2020 data as a benchmark for decennial planning. • Tonnage is not and should not be used as the single metric to measure material and waste management program performance.
The availability and quality of waste stream data vary by generation activity (sector) and by service provider.	• Consistency and enforcement of data reporting is needed.
Higher volume of refuse and commodities were collected by the Chicago from single-family (SF) residential homes in 2020, compared to 2019 and predicated value in 2020 from time-series modeling.	• While the locations of waste generation have shifted towards residences during pandemic conditions, education programs for City residents can be particularly important.
Multi-family (MF) residential units in Chicago steadily increased between 2010 and 2020, so did residential waste.	• Given many documented challenges of MF residential recycling nationwide (e.g., NYC Bureau of Waste Prevention, Reuse and Recycling, 2001), additional resources and educational programs may be needed to advance residential recycling goals in Chicago.
On average, each Chicago resident generates a little over 3 pounds (lbs) of waste per day at home, or a little under 3,000 lbs of waste per year for each Chicago household. Compared to other peer cities and regions (e.g., NYC and California), residential waste generation rates in Chicago are higher (NYC Department of Sanitation, 2018; CalRecycle, 2021).	• There are potentials for source reduction from Chicago residences.
After the Chicago Blue/Black Cart Program expanded from limited coverage to city-wide implementation, commodity volume collected per household for recycling decreased, which suggests the increases in recycling participation did not keep up with the City's recycling program expansion. The decreasing trend of recycling performance turned around in 2018, when the City launched community campaigns to boost residents' participation in recycling and to reduce contamination.	• Community education programs matter.

Table ES-1: Key Findings and Recommendations (2 of 3)

Key Findings	Recommendations
Blue Cart program performance varies across the six service regions in the City.	• Additional data and further analysis (e.g., demographics, public vs. private operations, market development, macroeconomic conditions) are needed to explore cost-effective and region-specific strategies to improve recycling performance.
About 522,510 tons of organic waste are estimated to be generated in Chicago every year, including 245,260 tons from SF residential, 81,250 tons from MF residential, and 196,000 tons from ICI sectors. Implementing source separation of 75% of organic waste from SF homes would boost landfill diversion rate by 18.6%.	• Implementing organic waste diversion programs has great potential to increase the diversion rates in Chicago.
Total employment in Chicago increased 2010-2018; employment in the Restaurant and Food industry had the fastest growth, by 28.29%. Consumer expenditure on Food away from Home increased 18.24%. Reported increases in food waste generation in the Illinois outpaced diversion efforts (CDM Smith, 2015).	• Increasing food waste volume and possible changes of generation location requires further analysis and proactive planning for food scrap as a target stream in Chicago.
Among different material classes generated from ICI sectors, Glass increased the largest, by 22.44% (from 37,389 tons to 45,779 tons).	• Increases in glass waste (despite the light-weight trend) in Chicago, the heavy weight of glass, and possible contamination of broken glass for profitable commodity items in the single-stream recycling suggests that glass waste should be another target for waste diversion program in Chicago.
The composition of C&D waste in the City changed over time. Between 2010 and 2015, the shares of C&D refuse and steel out of the total C&D waste decreased; the shares of asphalt, concrete, and wood increased. Information after 2015 is not available or consistent for a comparison.	• Enforcement is needed for waste data reporting. Consistency and clarity in the reporting forms are important.
Building C&D waste generation in Chicago is estimated to be at 1.31-1.42 million tons annually. Additional information is needed for a reliable estimate for C&D waste from other activities (e.g., road and bridge construction and maintenance).	• Besides building C&D waste, more specifics are needed for other types of C&D waste in the Chicago city ordinance.

Table ES-1: Key Findings and Recommendations (Continued, 3 of 3)

Key Findings	Recommendations
Fast fashion and synthetic fabrics have presented challenges for textile waste management. Uses and discards of masks have significantly increased during pandemic conditions. Statewide, Illinois (CDM Smith, 2015) saw increases in textile recovery/diversion rate increased from 2.0% in 2008 to 19.0% in 2014. Clothes and lines are not accepted by the Chicago Blue Cart program.	• New programs for textile reuse and diversion may be needed to address the lagging performance of textile waste management.
The amount of MSW generated per dollar spent is decreasing (US EPA, 2020). Light-weighting trends of electronic products discourage manufacturers from recycling, given that the Illinois legislation is based on the weight of electronics sold (Ruppenthal, 2017). Light-weighting of bottles has offset an increase in bottle uses (Association of Plastics Recyclers, 2019; Rue, 2018).	• Light-weighting material trends present an important confounding factor for the traditional approach of measuring material and waste management by weight (tonnage) only. Additional studies are needed to assess the impacts of light-weighting trends.
Nationwide, some materials showed opposite trends of recycled volume and recycling rates. For example, the recycled volume of metal and textile increased but the recycling rates dropped in the last decade (US EPA, 2020).	• Multiple metrics (instead of one single metric of waste tonnage or recycling rate) should be analyzed. Environmental life cycle impacts and socioeconomic impacts should be also considered on a case-by-case basis.
Pandemic conditions changed not only the waste volume but also composition and location. Documented increases in waste from home renovation projects and packaging materials from takeout food and online shopping, but lack of recycling knowledge from residents (Cruden, 2020; Porter and Holder, 2020).	• Additional efforts and resources are needed to support residential recycling during pandemic conditions.

Note: All waste volumes are in US short tons.

1. Introduction

In partnership with the Delta Institute for a 2020 Chicago Waste Strategy Study, the team at the University of Illinois at Chicago (UIC) was tasked with developing a profile about Chicago waste generation and characterization. The UIC team had four specific tasks during the five-week project period (1/25/2021-2/26/2021):

- Task 1: Estimate annual overall waste generation in 2020
- Task 2: Identify increasing or decreasing trends by material type
- Task 3: Summarize material or diversion innovations in the past decade that significantly impact the material disposal
- Task 4: Summarize consumer expenditure data that delineate impacts on waste generation

Because a full-scale waste audit was not feasible in 2020, the UIC team was directed to provide estimates for 2020 based on Chicago historical data, along with regional and national datasets. The following sections report on our methodology, raw data used, estimation results, and key findings from both quantitative and qualitive analyses.

While it can be appealing to compare the estimation results in 2020 in this report to past or future years, it is important to note that the tonnage is not and should not be regarded as the single metric to measure waste performance or impacts, for multiple reasons (e.g., material light-weighting trend and varying life cycle impacts across material classes and uses). Notably, COVID-19 pandemic conditions in 2020 may also have changed the waste stream, as well as waste management services, from fairly stable and predictable patterns in the past decade. Findings from our data analysis generally confirm the changes reported by waste professionals in anecdotal cases (e.g., more waste is generated from residential locations than an average year and more details in Section 4.2). However, the full magnitude of the impact of COVID-19 on material and waste management has yet to be explored.

It is also important to clarify that the total waste volume estimates in this study are mainly for the purpose of and tasks specified in the 2020 Chicago Waste Strategy Study. For cross-region comparisons, results should be interpreted with caution and additional calculations may be needed. Definitions and classifications of municipal solid waste (MSW) can vary across jurisdictions and over time (Ai and Leigh, 2017). Although this project has attempted to analyze and report data in a consistent way as in historical reports, adjustments had to be made, in particular, regarding the construction and demolition (C&D) waste. Because the nature of C&D waste (heavy and bulky), waste characterization and generation volumes can be significantly affected by the C&D content.

Prioritizing the waste streams that have been documented by verifiable data, the numerical analysis in this study only included C&D waste from buildings; C&D waste generated from other activities (e.g., road construction or maintenance) are excluded. Therefore, it is inappropriate to compare the total waste volume estimates in this study to the national average or other regions' data in which MSW is defined in a different way (e.g., the United States Environmental Protection Agency, the US EPA, excludes C&D waste from the national MSW estimates).

Alternatively, for policy and planning purposes, single sector- or activity-based volume estimates involve less uncertainties and thus tend to be more robust than the total aggregated waste volume. For example, the quantity of organic waste from the residential sector provides policy insights to strategic planning. As discussed previously, pandemic years can be outliers and may not be suitable as a benchmark for decennial planning.

2. Overall Project Design

Under data constraints, the scope and design of this project are developed to address the four tasks specified by the Chicago Waste Strategy Study led by the Delta Institute. The methodology of numerical analysis was developed with the intention of replicability, i.e., focus is given to input datasets that are commonly available overtime. This will allow the City of Chicago and other communities to evaluate and report material and waste data using a consistent methodology year over year.

For Task 1, waste volumes need to be estimated because waste generation statistics are not commonly available at local or regional levels in the U.S. and waste characterization studies are not regularly conducted due to intensive requirements for labor and resources (Ai and Leigh, 2017). The Chicago 2010 Waste Diversion Study (CDM, 2010a) provides a discussion about the complexity of waste stream data in the case of the City of Chicago. Chicago waste is managed both by the City and private haulers, not all of which have been reporting waste quantities or flows to the City. While underreporting suggests a lower estimate of total waste volume, there are other factors that possibly contribute to double counting. For example, waste processed by Chicago area haulers does not necessarily originate within the City limits. Hauler reports may also include recycled materials that are backhauled to other locations. Eventually, not all materials collected for recycling are recycled. Therefore, the total tonnage as reported by all waste collection service providers does not represent the overall waste generation.

This study analyzes the data reported by the Chicago Blue Cart Program (managed by the City) and private haulers, and further, develops estimates using time series analysis to fill in data gaps and to make necessary adjustments. The total waste volume is the sum of refuse (destined for disposal) and commodity (collected for recycling) from all MSW generators in the City. Data in the 2010 Chicago Diversion Study (CDM, 2010a) and 2010 Chicago Waste Characterization Study (CDM, 2010b) were adopted as the baseline for this 2020 study update. As such, this project has adopted the definitions, material, and sector classification systems in the Chicago 2010 reports (provided in Appendix) to the extent possible. Various methods for volume estimates are tested for each sector in this study, and modeling results are validated using local data whenever possible. Given varying availability and quality of data by sector, there are various levels of confidence in data estimates by sector.

Task 2 requires the information about the composition of the Chicago waste stream. While the US EPA has adopted a commodity-based approach for waste composition estimates of a national average, economic data at the local level are inadequate to support this approach. Thus, periodical waste auditing is often the resort. The last waste characterization study in Chicago was prepared by CDM in 2010. A total of 535 waste samples were hand-sorted, or visually inspected by volume, and characterized into ten material classes at 14 solid waste facilities (CDM, 2010a). The sampling plan was intended to represent waste generated from various sectors (i.e., residential, institutional, commercial, industrial, and construction and demolition waste) and various ward characteristics (i.e., average household income and curbside recycling availability). Besides the 2010 Chicago waste studies, the City has collected limited data that characterize the waste stream by material class. However, the categorization methods have been inconsistent over time and thus would not allow for a trend analysis. Numerical estimates of material-specific volumes are limited to ICI sectors, when waste volumes are linked to employment size by sector. For a qualitative analysis for Task 2, this study refers to federal and state reports, academic research, industry surveys and reports, and well-regarded industry magazines as well as major news outlets.

For Task 3, two different types of innovations and changes are reviewed in this report: (1) product innovation (e.g., light weighting of materials); and (2) programs and policies (e.g., plastics bag fees, Blue Cart program expansions, and landfill bans). In other words, innovations/changes can be technological or institutional. Given the large scope of the topic, our summary report only focuses on innovations that have “documented” impacts on the diversion performance in the past decade. The goal is to identify the most influential factors that affect specific types of materials (e.g., C&D, organics, and plastics), instead of an exhaustive list for all types of programs nationwide. It is important to note that not all the “innovations” or “changes” are progressive for various reasons (e.g., budget constraints, administration transition/changes, and pandemic conditions). The review aims to focus on notable innovations/changes that have occurred, may have affected, or can be possibly applicable in the Chicago region. Thus, nationwide and Illinois state practices are also reviewed and discussed.

Task 4 is conducted in a parallel process to Task 2 and aims to boost the literature review in Task 2 by a quantitative analysis of consumer expenditures and patterns over time. In a coordinated approach, Tasks 2-4 aim to make some important clarifications about changes that cannot be quantified but appear to be confounding factors when interpreting the results solely in the unit of material weight (tons).

Given the connectiveness of various task elements, our results and findings from the four tasks are re-grouped in the two sections as follows: Section 3 focuses on sector-based waste volume estimates in numerical terms; Section 4 focuses on material-specific analysis, both qualitative and quantitatively.

3. Chicago Waste Volume Estimates

As explained earlier, this project aims to follow a consistent system of sector and material definitions as the Chicago 2010 studies (CDM, 2010a and 2010b), which includes three general categories, definitions in Appendix:

- Residential waste, which is further categorized into single-family (SF) and multi-family (MF) residential;
- Institutional/commercial/industrial (ICI) waste;
- Construction and demolition (C&D) waste;

Besides SF and MF residential, ICI, and C&D waste volumes, this study also develops estimates for yard waste and overall organic waste, which possibly have been on a rising trend given several identified factors (e.g., rapid growth in restaurant and food industry employment and increases in consumer expenditure on food away from home, more details in Section 4).

To avoid double counting, the total waste volumes are calculated based on the generators (i.e., sectors) instead of materials (i.e., yard waste volume is calculated as part of the SF residential waste volume and thus is not added as a separate category). The following sub-sections report on varying levels of reported data availability and quality, volume estimation methodology and results, starting with a grand total. All the tonnage values are in US short tons in this report.

3.1 Total waste volume

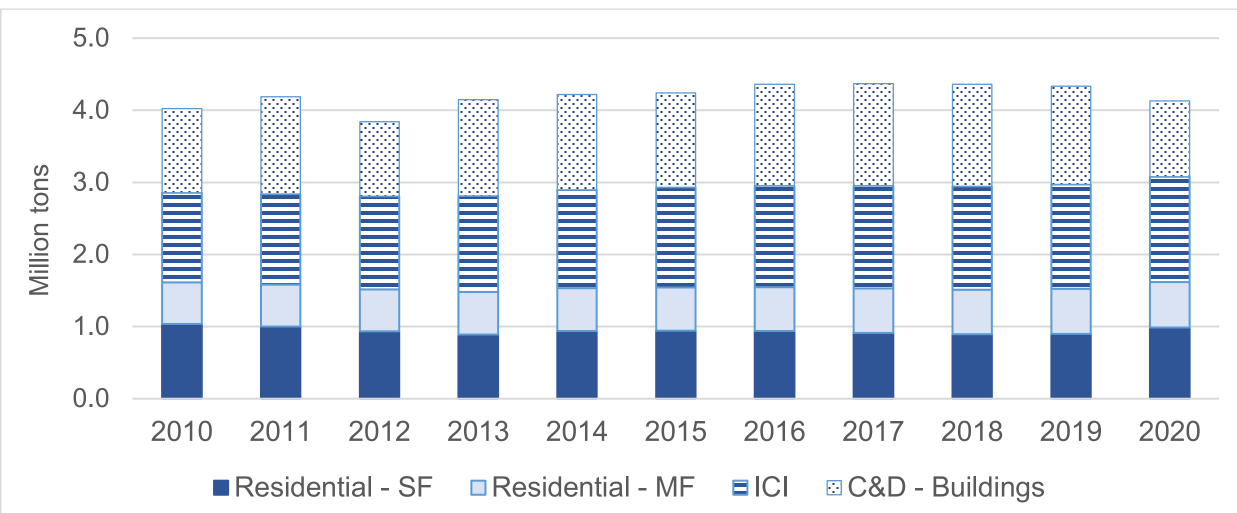
In the 2010 Chicago waste studies (CDM, 2010a and 2010b), total waste generation includes residential waste (from both SF and MF homes), ICI waste, and

C&D waste. All the results in the 2010 studies are estimated for the year 2007, when Chicago is estimated to have generated a total of 7.67 million tons of waste, including 1,103,025 tons (14.4%) of City collected SF residential waste, 576,529 (7.5%) of privately collected MF residential waste, 1,332,507 tons (17.4%) from privately collected ICI, and 4,656,037 tons (67%) from C&D (CMD, 2010b).

For this 2020 Chicago waste generation study, total waste generation includes the same categories as of 2010, but the scope is different for the C&D waste. Only C&D waste from buildings are estimated in the 2020 study; other types of C&D waste (e.g., roads and bridges) are excluded due to data constraints and anticipated risks of compromising the confidence level of total waste generation estimates given the heavy material weight of C&D waste. Section 3.5 in this report provides more details about the scope used in this study and rationale.

Figure 1 below shows the annual waste estimates between 2010 and 2020. Overall, there is an increase in waste generation in the last decade. Yearly fluctuations of waste generation volume seem to respond to economic conditions. The City of Chicago generated 4.13 million tons of waste in 2020 (estimated in this study), compared to 4.02 million tons in 2010 (backcasted in this study using the consistent method for 2020 estimates). Caution should be given when interpreting waste volume in 2020, given COVID-19 pandemic conditions.

Figure 1 Chicago Annual Waste Generation (2010-2020)



SF: Single family homes (typically with four or fewer units) where waste is collected by the City Department of Streets and Sanitation (DSS). MF: Multi-family homes where waste is collected by private haulers. ICI: Institutional, Commercial, and Industrial. C&D: Construction and Demolition. Data are compiled from various reports from the City of Chicago to the extent possible; incomplete data in city reports are estimated by the UIC team.

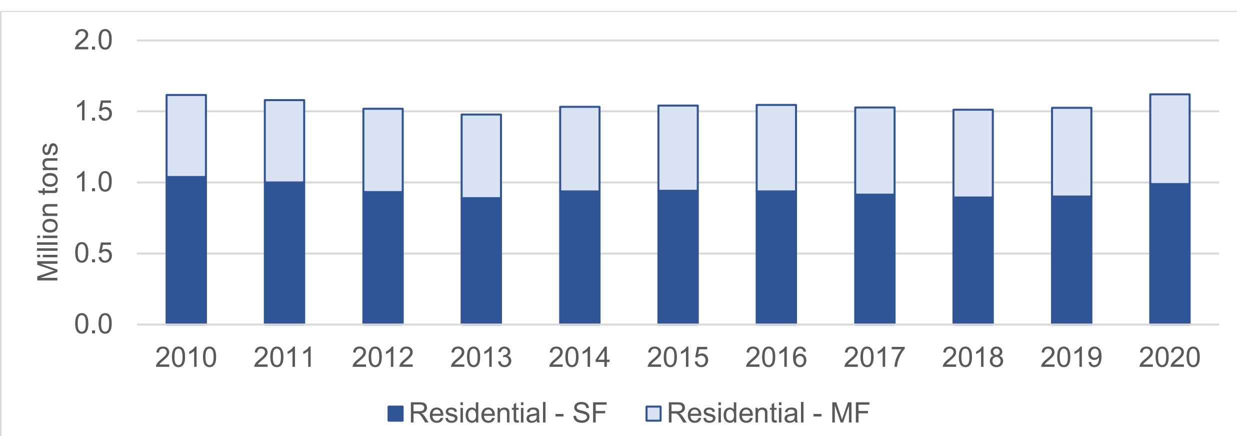
Combing residential and ICI sectors, the total yard waste generation from Chicago is estimated at about 71,010 tons a year. Further, a previous study by Ai and Zheng (2019) estimated food waste generation in Chicago at 451,500 tons per year, including 203,130 tons from SF residential, 64,470 from MF residential, and 183,900 from ICI sectors. Combining the estimated volume of yard waste and food waste, it is estimated that about 522,510 tons of organic waste are generated every year, including 245,260 tons from SF residential, 81,250 tons from MF residential, and 196,000 tons from ICI sectors. In other words, implementing source separation of 75% of organic waste from SF homes would boost landfill diversion rate by 18.6%.

3.2 Residential Waste

Residential waste is collected by both the Chicago Department of Streets and Sanitation (DSS) and private haulers. The DSS services SF homes or apartments with four units or less; private haulers manage MF residential waste together with ICI waste. Therefore, residential waste streams are documented by the City separately and analyzed separately in this project. SF residential waste volume is recorded by the City; MF residential waste volume is estimated in this project.

Figure 2 presents the total of residential waste, i.e., managed by both the City and private haulers, between 2010 and 2020. In 2020, SF residents generated 989,924 tons of waste; MF residents generated 629,735 tons of waste (95% confidence interval, CI, ranging from 626,910 to 632,560 tons). As reported by the City, SF residents generated 9.89% in 2020 more waste than 2019 (at 900,862 tons). The increase may be partially a result of lockdown policy and remote working conditions during COVID-19.

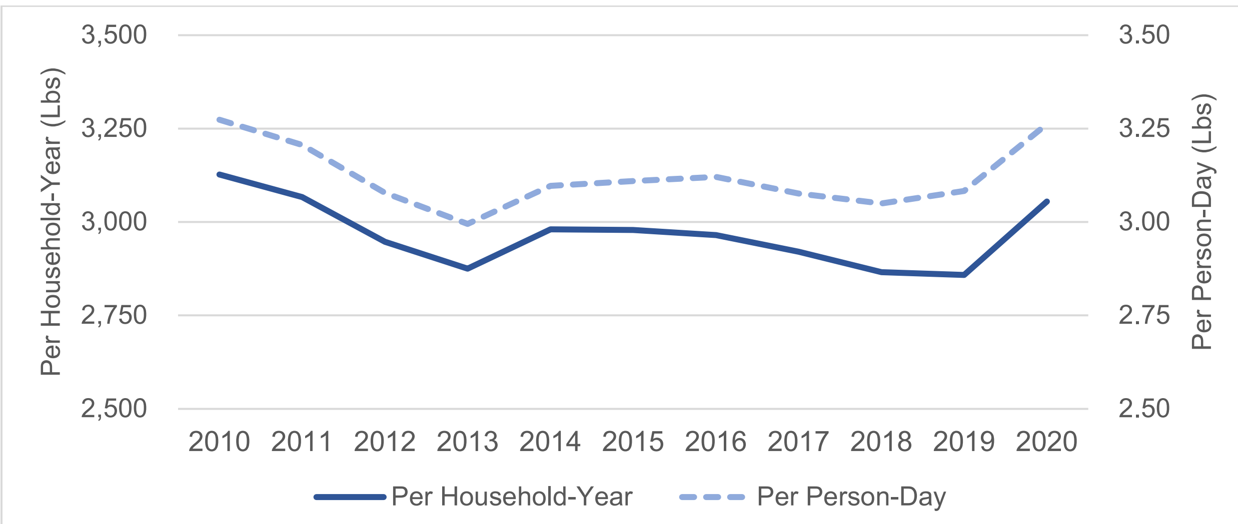
Figure 2 Chicago Residential Waste Generation (2010-2020)



Note: SF volumes are reported by Chicago DSS. MF volumes are estimated by the UIC team, using an extrapolation method based on changes of MF units.

In normalized measures (Figure 3), residential waste generation (by population and household) has shown a decreasing trend in the last decade, except for 2020 (possibly due to the COVID-19). On average, each Chicago resident generates a little over 3 pounds (lbs) of waste per day at home, or under 3,000 lbs of waste per year for each Chicago household. For clarification, these normalized rates refer to residential waste (generated from SF and MF homes) only, which is only part of MSW. Compared to other peer cities and regions, residential waste generation rates in Chicago are higher than those in NYC and California (NYC Department of Sanitation, 2018; CalRecycle 2021). This suggests potential opportunities for source reduction from Chicago residents at home.

Figure 3 Residential Waste Generation Rates per Household and per Person (2010-2020)



Note: SF waste data are reported by the City. MF waste data are estimated by the UIC team. Data of population and households in Chicago are from the US Census American Community Survey (ACS) 5-year estimates (2010-2019). The 2020 demographics are estimated by the UIC team.

3.2.1 DSS Collected Single Family Residential Waste

The Chicago DSS collects waste from homes that are typically with four or fewer units. Rolled out in 2007, the Chicago Blue Cart program collects refuse; the Black Carts collect commodity for recycling. The coverage of Blue/Black Cart services expanded moderately afterwards. In 2011, the City initiated managed competition of waste collection services that involved private sectors. In 2013, the City had a major expansion. Since October 2013, the Blue/Black Cart program have been covering the entire city. The City initially included yard waste in the Blue Cart program but reduced the efforts in the following years. After 2015, yard waste has been collected only by work orders (i.e., upon SF resident request).

The total volumes of SF residential waste generation include refuse collection, commodity collected for recycling, and yard waste (collected by work orders). Monthly collection volume of the Blue/Black Cart services has been recorded by the City. This is the most and only complete set of waste records across waste generation sectors in Chicago. Section 3.2.1.1 summarizes the City recorded data and explores the possible impacts of COVID-19 on residential waste generation. Section 3.2.1.2 analyzes the Blue/Black Cart program performance since the program implementation, which also provides another opportunity to analyze waste volume in a normalized measure (i.e., per household). Section 3.2.1.3 has a target analysis of yard waste, which shows the largest variations in reported data over time.

3.2.1.1 DSS SF Refuse and Commodity Volume

While the City records monthly volume of refuse and commodity from DSS collected SF homes, this project also develops a time-series analysis that is anticipated to reveal possible impacts of COVID-19. The assumption is that the difference between Chicago reported data in 2020 and predicted volume of time series modeling can be partially resulted from the pandemic condition, if the predicted values from the time series in pre-COVID years match the historical data.

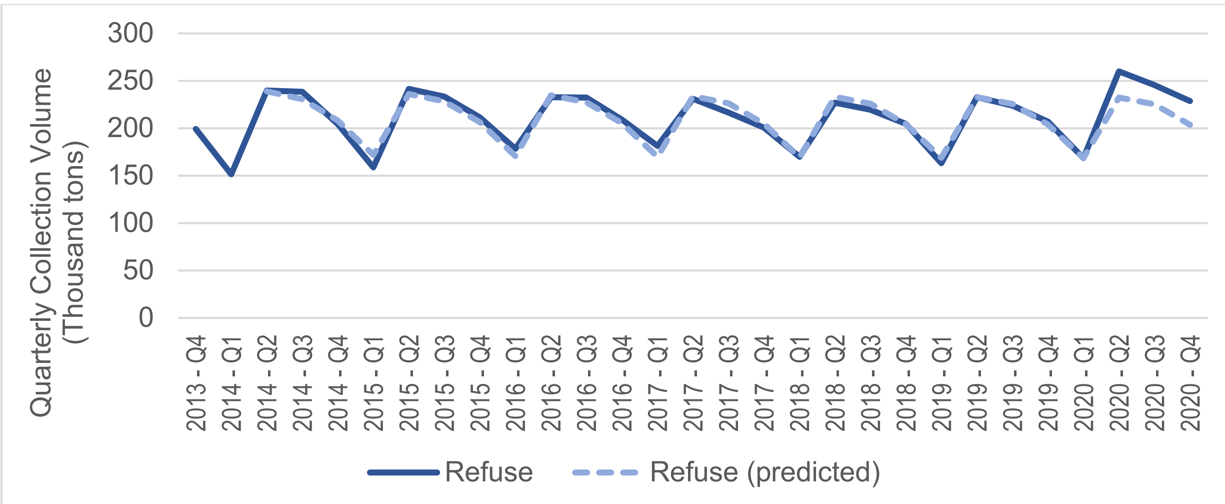
In Figures 4-5, both reported (solid line) and modeled (dashed line) volumes are plotted at a quarter interval after 2013, when the Blue/Black Cart program began to cover the entire city. The refuse volume from the time-series modeling fairly matched the recorded collection rates between 2013 and 2020 (with a R-square of 0.94). In 2020, the time-series model estimated the refuse collection volume of 829,844 tons (the total of four quarters), compared to the actual collection volume of 902,851 tons. The 8.80% difference between the estimated value and actual value of refuse volume likely reflects the impact of COVID-19.

In terms of commodity for recycling, the time-series results generally match the actual data, except for 2018 when service disruptions were reported (due to fire at a recycling facility). Similar to the case of refuse, the estimated tonnage for commodity (78,470 tons) was lower than reported volume (86,477 tons) in 2020, i.e., a 10.20% difference that is possibly associated with COVID-19.

3.2.1.2 DSS Service Levels vs. Waste Material Collection

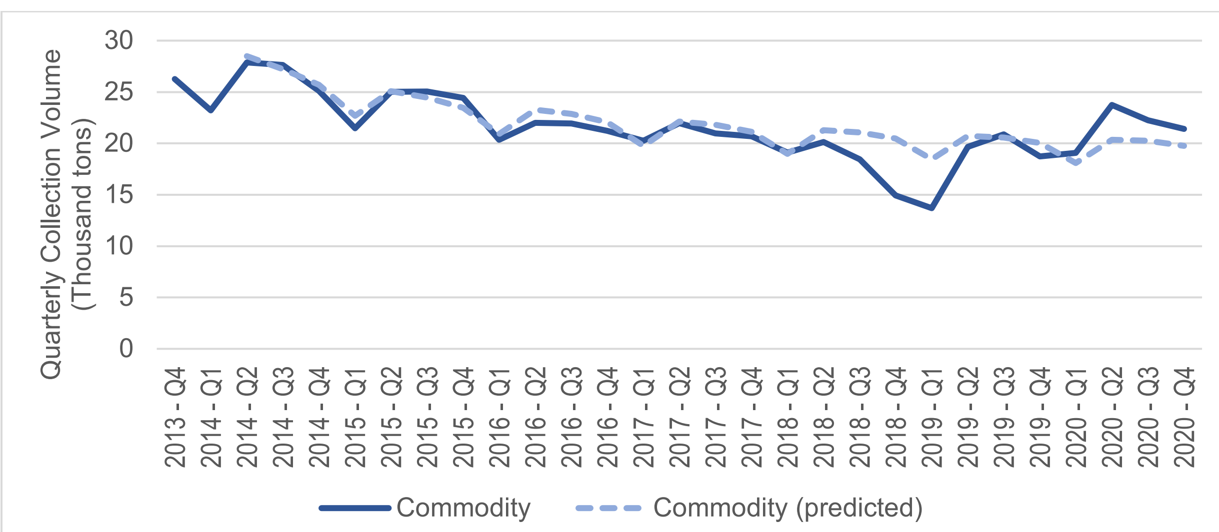
For a better understanding of the DSS SF residential waste trends, the number of DSS served homes and SF residential material collection since the beginning of the City Blue/Black Cart operation in 2007 are analyzed. As shown in Figure 6, the level of material collection seems to be generally consistent with the number of homes for which DSS has provided waste collection services. The volume of materials collected fluctuates considerably by season.

Figure 4 DSS SF Residential Refuse Volume (2013-2020)



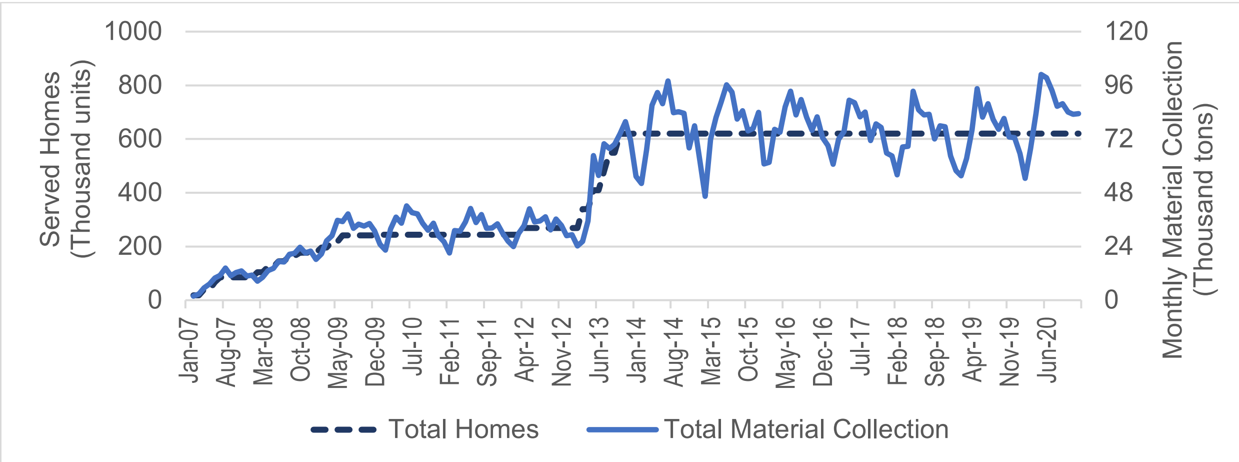
Refuse volume (solid line) recorded by the City; the predicted volume (dashed line) is resulted from the time series modeling in this project.

Figure 5 DSS SF Residential: Volume of Commodity Collected for Recycling (2013-2020)



Refuse volume (solid line) recorded by the City; the predicted volume (dashed line) is resulted from the time series modeling in this project.

Figure 6 Number of DSS Served Homes vs. Monthly Total SF Residential Material Collection (2007-2020)



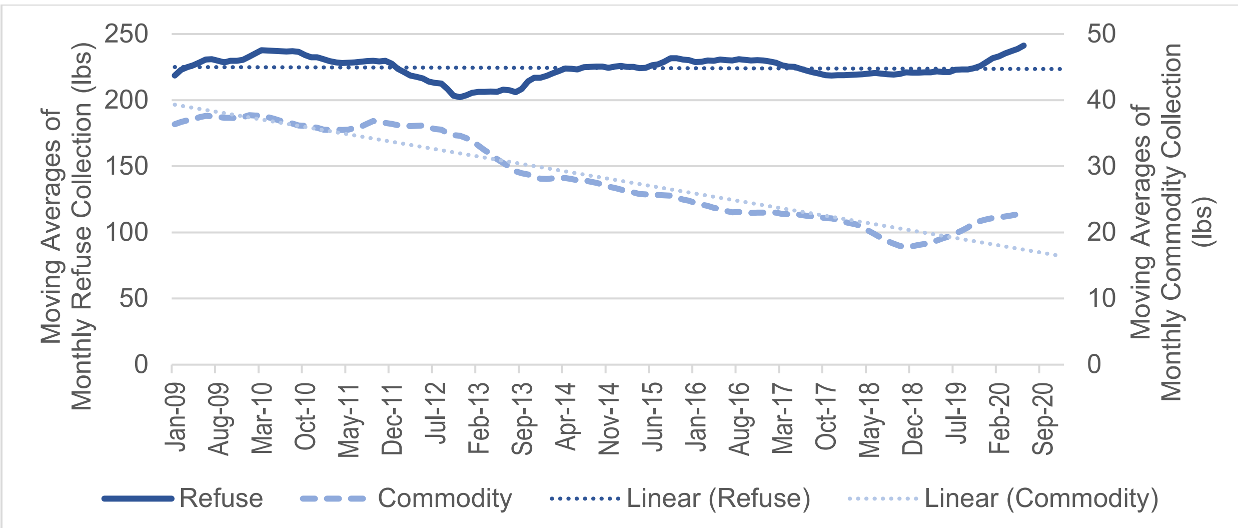
Note: Total material collection includes refuse, commodity, and yard waste from SF homes where the City has provided waste collection services. Data are provided by the City. Chart is produced by the UIC team.

The DSS SF residential trends were also measured in normalized measures (i.e., per capita and per households) (Figure 7). After the Blue Cart Program coverage significantly expanded in 2013 (shown in Figure 6), per household refuse collection volume has remained relatively stable (until 2020). Per household commodity volume collected for recycling decreased, which suggests the increases in commodity volume collected did not keep up with the increase in the City's recycling program expansion. The decreasing trend of recycling performance turned around in 2018, when the City launched community campaigns to boost residents' participation in recycling and to reduce contamination.

For refuse, the linear predictions show an average of 819,976 tons in 2020 (95% CI from 761,244 to 878,709 tons), which generally confirms the time-series modeling result in Figure 4 (829,844 tons). Regarding commodity collected for recycling, the linear model shows an average of 58,595 tons in 2020 (95% CI from 48,520 to 68,671 tons). This is lower than the time-series modeling result in Figure 5 (78,470 tons), possibly because the linear predictions cannot capture increased efforts of recycling services in recent years. In general, the time-series model seems to produce a more accurate prediction of waste volume than the per-household approach.

Further, Blue Cart Program performance is examined by waste service regions. As shown in Figure 8, there is a general trend of declining performance while some service regions show relatively consistent performance over time. Blue Cart program recycling rates varied across the six service regions in the City between 2014 and 2019. Many factors may affect the varying and lagging program performance, for example, possible differences in operation efficiency and effectiveness across DSS and multiple private vendors, neighborhood characteristics (demographics, recycling participation, and waste composition), staggering landfill tipping fees in the region, macroeconomic conditions, overseas waste import restrictions, as well as light-weighting material trends. Therefore, additional data and further analysis are needed to explore cost-effective and region-specific strategies to improve recycling performance.

Figure 7 DSS SF Refuse and Commodity Collection Trends per Household (2009-2020)



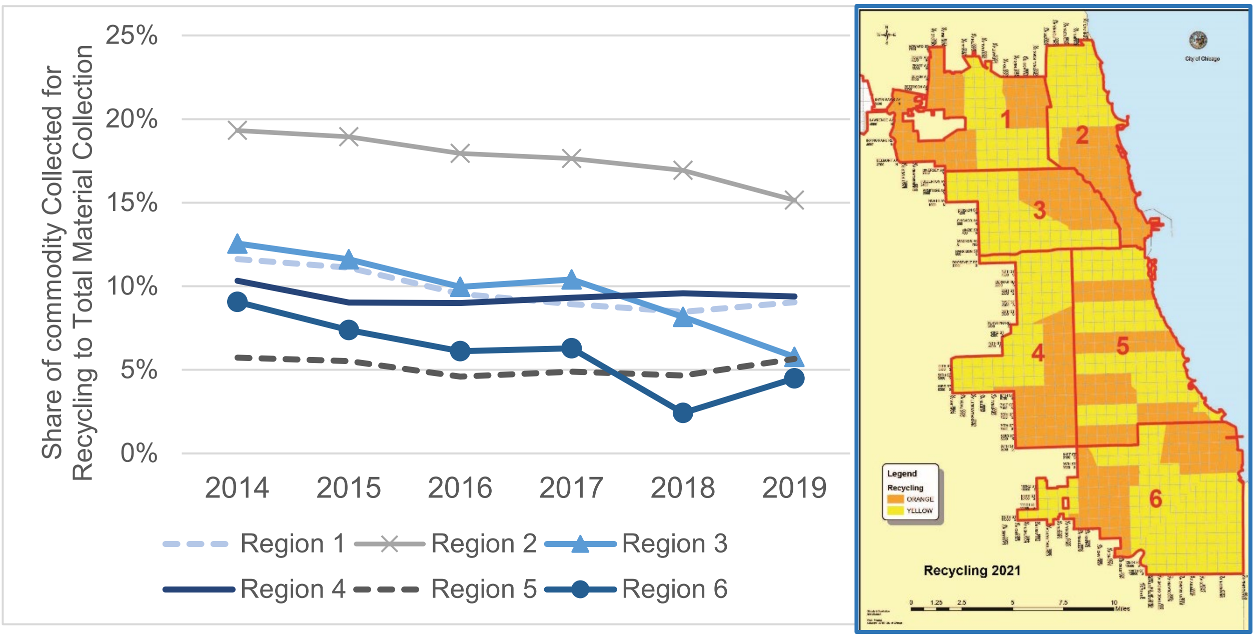
Note: Refuse and commodity volume from single family homes are recorded by the City. Per household rates and chart are produced by the UIC team. Twelve-month moving averages are adopted to address the seasonal effects. Per household rates were calculated as the data input of the second method for the DSS SF residential waste analysis (compared to Figures 4-5).

3.2.1.3 Yard Waste Volume Estimates

While there are no separate bins designated for yard waste collection from single residential homes since 2015, the City has been responding to residential requests for pick up services. There have been large variations of reported volume year over year, and not all yard waste generated is collected.

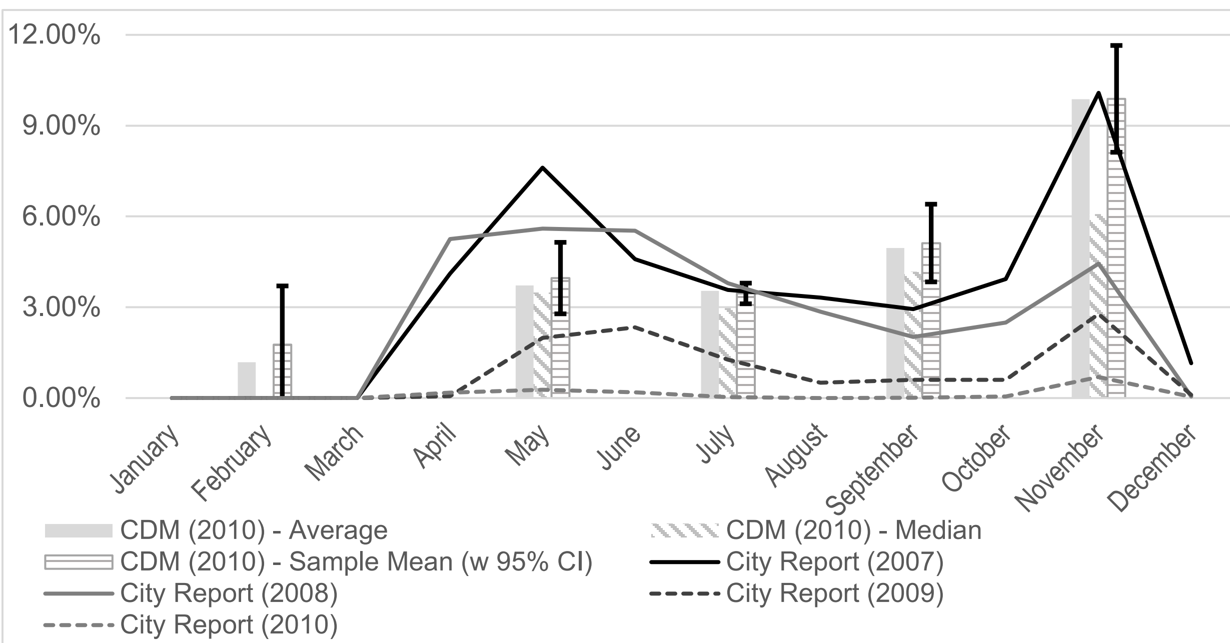
For an estimate of the yard waste generation volume, various references and documents of yard waste generation in Chicago are collected and compared. Reported shares of yard waste out of the total materials collected seem to be relatively consistent across references (Figure 9). In Chicago, it seems that yard waste accounts for 4-6% from April to September and can be close to 10% in late fall. Based on the literature review (Figure 9), this project adopts the estimated values in Table 1 for yard waste generation from DSS SF residential homes.

Figure 8 Blue Cart Program Performance by Chicago Waste Service Region (2014 – 2019)



Data provided by the City; Chart by the UIC team. Map from ChicagoRecycles.org.

Figure 9 Reported Shares of Yard Waste among Total Material Collected: A Review



Note: This figure shows the proportion of yard waste in the total materials collected on a monthly basis. Yard waste rates in Chicago as reported from various data sources are compared. Chart is produced by the UIC team.

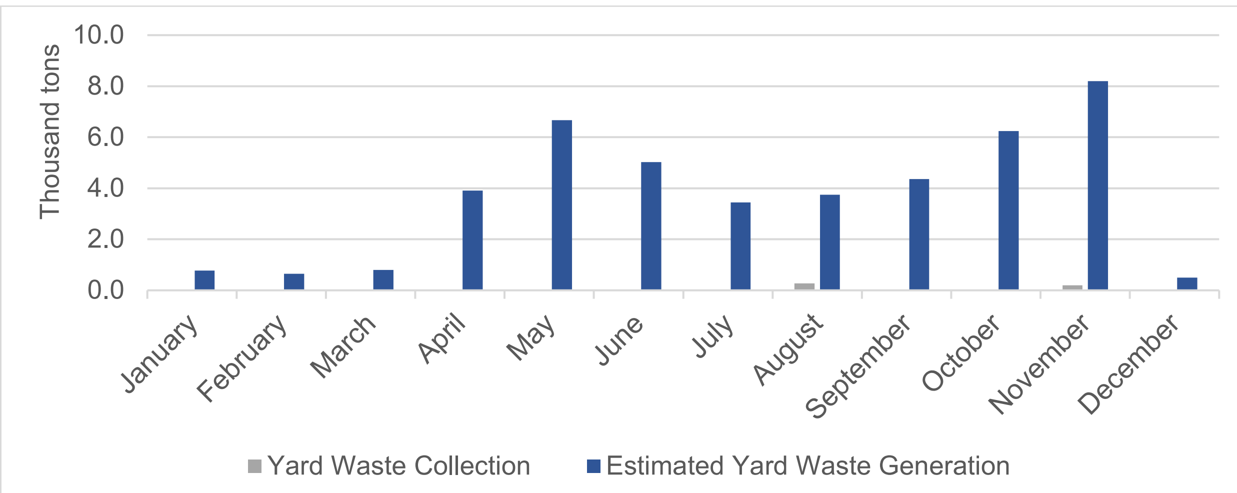
Table 1 Estimated Shares Yard Waste among Total Material Collected in Chicago

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1.18%	1.18%	1.18%	4.69%	6.61%	5.06%	3.68%	4.32%	4.96%	7.42%	9.87%	0.60%

Note: The values are estimated by the UIC team based on references in Figure 9 and are used as input parameters for yard waste estimates in Chicago (Figure 10).

Annually, an estimated volume of 39,956-44,306 tons of yard waste are generated from SF residences (with 4 units or under) in Chicago, but very little has been collected or managed separately from refuse. Monthly yard waste generation can be as low as 503-801 tons in winter months, compared to 3,912-6,662 tons in late spring/early summer, and 4,359-8,203 tons in late fall (Figure 10).

Figure 10 Estimated Yard Waste Generation from Single Family Residences in Chicago vs. Volume Collected by Work Orders



Note: Monthly yard waste generation volumes for single family homes are estimated by multiplying total material collection by the ratios presented in Table 1. Yard waste collection volume (per work order) is recorded by the City. Chart produced by the UIC team.

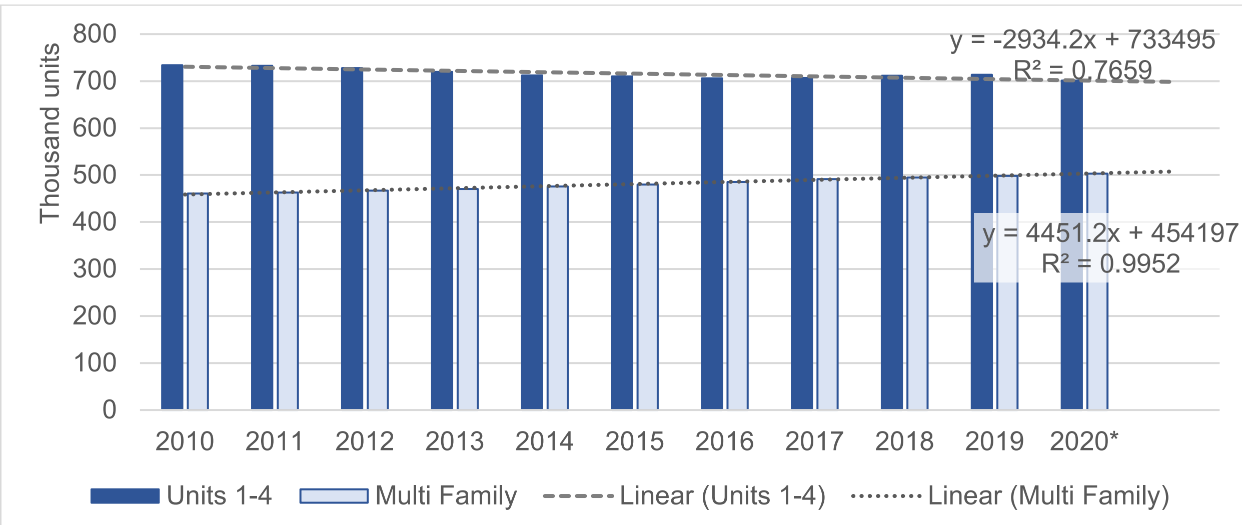
3.2.2 Multifamily Residential/Privately Collected Waste

Because private haulers do not differentiate MF residential waste from the ICI waste stream at the time of collection, this project develops annual estimates based on the number of MF housing units in Chicago.

The US Census American Community Survey provides the number of housing units annually in Chicago from 2010 to 2019. The project extrapolates the data to 2020 using time series modeling.

As shown in Figure 11, MF housing units increased from 460,648 units in 2010 to 503,160 units (estimated) in 2020, or by 9.23%. Accordingly, the total waste generation from MF units is estimated to have increased between 2010 and 2020, when it reaches 629,735 tons. In contrast, SF housing (with 4 units or under) decreased from 734,220 units in 2010 to 701,219 (estimated) in 2020, or by 4.49%, in Chicago. After vacant rates are adjusted, occupied SF housing units have been relatively stable and close to the number of homes covered by the City Blue Cart Program (620,313 units).

Figure 11 Trend of Housing Units in Chicago



Note: 2010-2019 data from the U.S. Census American Community Survey (Table DP-04); 2020 data estimated by the UIC team. Data are unadjusted for vacancy. Chart by the UIC team.

3.3 Institutional/Commercial/Industrial Waste

The MSW waste from ICI sectors is managed by private haulers. The completeness and details of material classes in the semi-annual reports vary. Due to irreconcilable inconsistencies in hauler reports and the confounding factors reported in the 2010 Chicago Waste Diversion Study, this study adopted a method that estimates waste volumes based on the employment size.

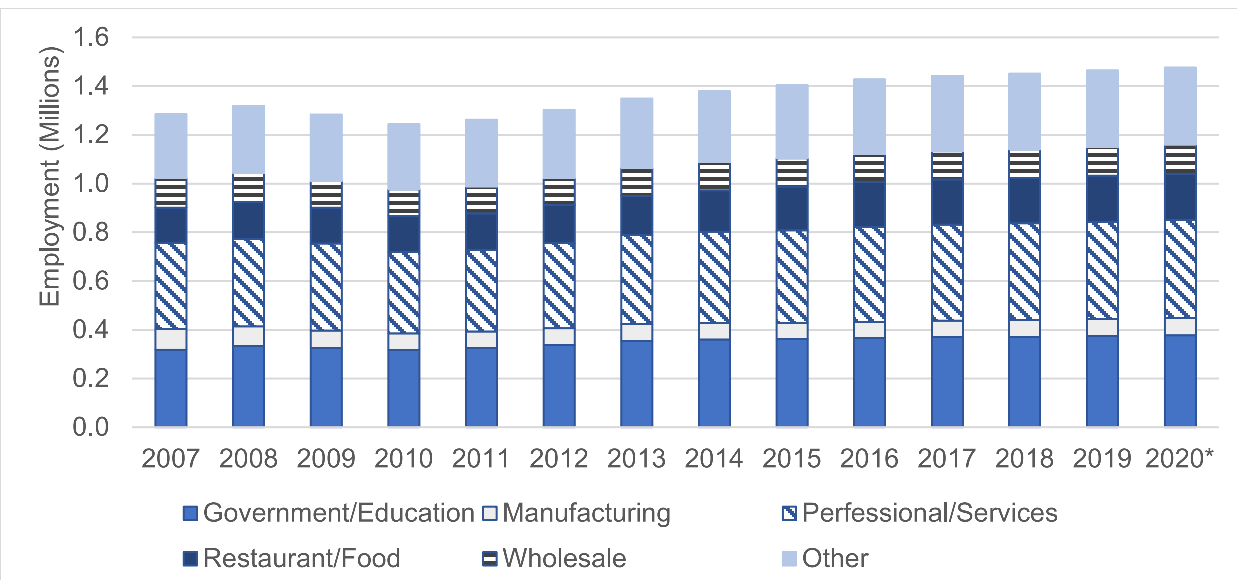
According to the ZIP Codes Business Pattern database, total employment in Chicago increased between 2007 and 2018, when the latest data are available. The ZIP Codes Business Pattern supports a city-level analysis, however, excludes government jobs (NAICS Sector 92: Public Administration & Government) and suppress some of the industry-specific employment data. To be consistent with the industry classification (five general groups, details in Appendix) in the 2010 Chicago Waste Characterization Study, this study develops methods to fill in the missing employment data by industry, to include jobs in the public sector, and further, to extrapolate data from 2018 to 2020. For consistency with the 2010 studies, employment in Agriculture, Mining, Utility, and Construction is also excluded in this study. After all these adjustments, it is estimated that the Chicago employment size increased from 1.24 million in 2010 to 1.47 million in 2020 (estimated, 95% CI for 1.41-1.55 million), or by 18.66% (Figure 12).

In particular, the Restaurant and Food industry and Professional/Service industry experienced the fastest growth between 2010 and 2020. Their employment grew by 28.29% and 20.54%, respectively. The manufacturing industry experienced significant job losses during the 2008 recession and remained stable afterwards (Figure 13).

Assuming constant rates of waste generation from each ICI sector between 2010 and 2020, ICI waste generation is estimated to have increased from 1,254,429 tons in 2010 to 1,456,708 in 2020 tons (95% CI 1,387,773 to 1,525,644 tons), or by 17.51%.

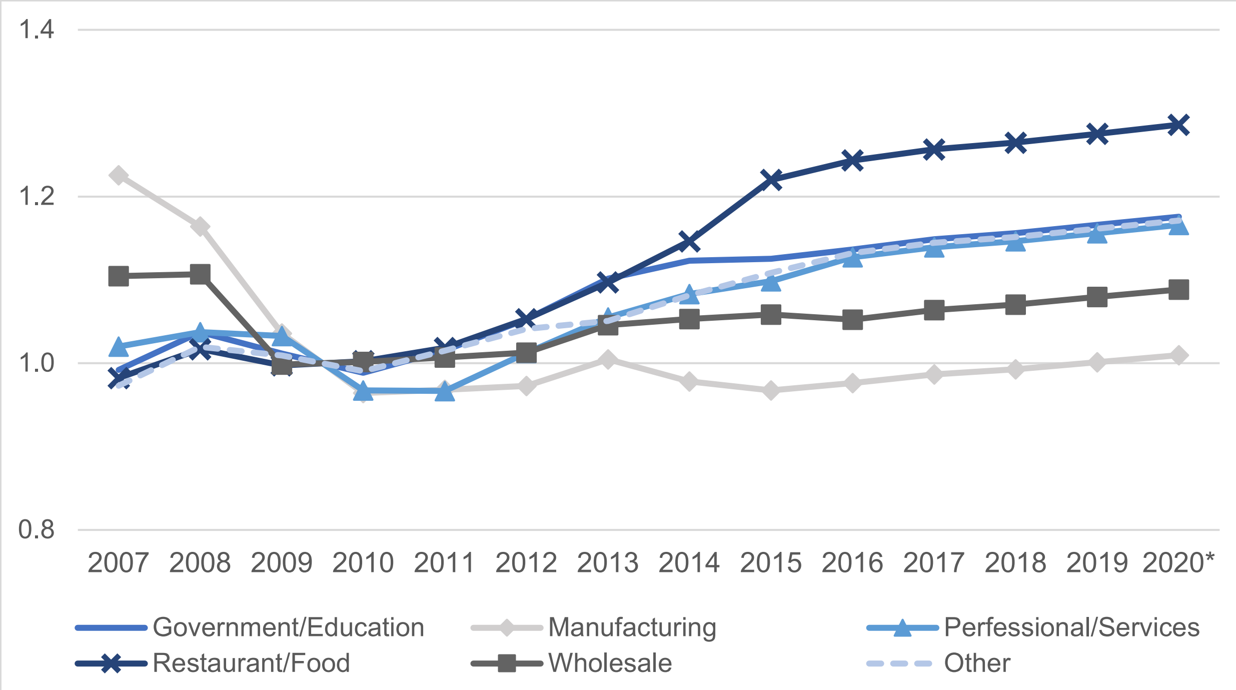
The ICI employment-based waste estimates also facilitate the material-specific analysis among different material groups. Results are shown in Figure 14. Between 2010 and 2020, it is estimated that Glass increased the most, by 22.44% (from 37,389 tons to 45,779 tons), followed by Organics (a 19.56% increase, from 318,834 to 381,199 tons).

Figure 12 Chicago Employment by Industry Groups (2007-2020)



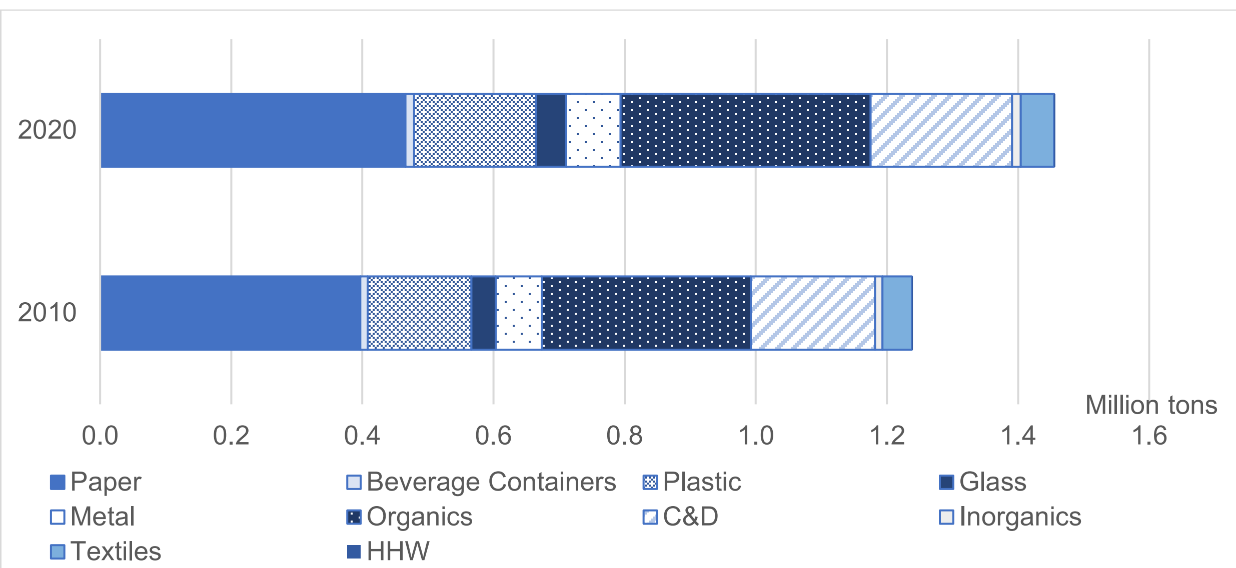
Note: Data compiled from the ZIP Codes Business Pattern (2007-2018). 2019 and 2020 data are estimated by the UIC team by adopting a linear regression.
* Impacts of COVID-19 on jobs are not adjusted.

Figure 13 Chicago Employment Changes by Industry Groups (2007-2020)



Note: Index values are developed by the UIC team using data from the ZIP Codes Business Pattern (2007-2018). 2019 and 2020 data are estimated by the UIC team by adopting linear trends. * Impacts of COVID-19 on jobs are not adjusted.

Figure 14 Estimated ICI Waste Generation Based on Industry Employment Changes (2010 vs. 2020)



Note: 2010 data from CDM (2010); 2020 data estimated by the UIC team. Chart by the UIC team.

3.4 Construction and Demolition Waste

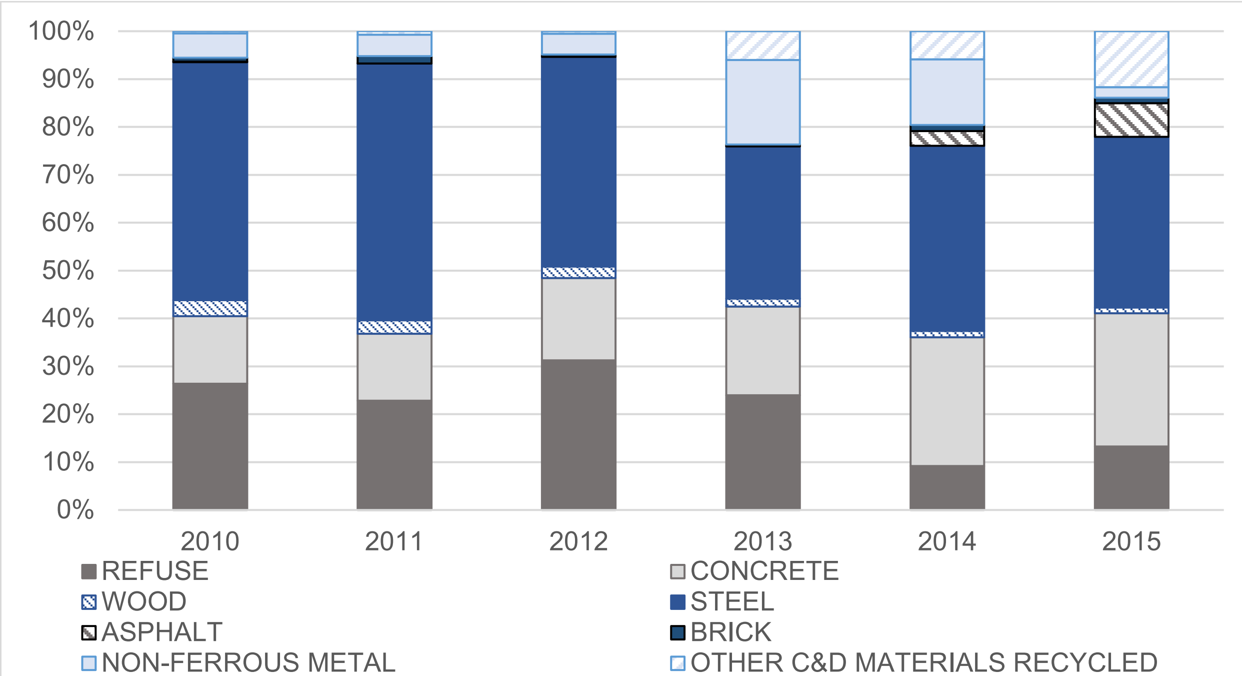
The C&D waste volume, regardless of generation location, is recorded as a separate category in private haulers' reports. Because not all haulers serving Chicago have provided reports, it is impossible to identify the total volume of C&D waste generation.

On the bright side, the C&D waste reports between 2010 and 2015 include specific material classification information (over 10 material types). Such information allows for an examination of C&D waste composition over time. As shown in Figure 15, the composition of C&D waste in the City has been changing over time. Between 2010 and 2015, the shares of C&D refuse and steel out of the total C&D waste decreased; the shares of asphalt, concrete, and wood increased.

C&D waste records after 2015, however, presented significant inconsistencies, which would not enable time series analysis in a reliable way or a replication of the 2010 Chicago studies. Therefore, this project develops two estimation methods. The first one refers to the parameters of material intensity and jobs at the national level in the US EPA (2018) study, which reports C&D waste from three activities: Buildings, Road and Bridges, and Other. This study matches the employment (by NAICS codes) related to these three categories and calculates the C&D tonnage per employment. While the building C&D tonnage per employment is relatively consistent, Road and Bridge and Other construction parameters yield very wide variations. For a reliable estimate of C&D volume estimate, this study only focuses on the C&D waste from buildings by multiplying the C&D tonnage per employment by the number of building construction jobs in Chicago.

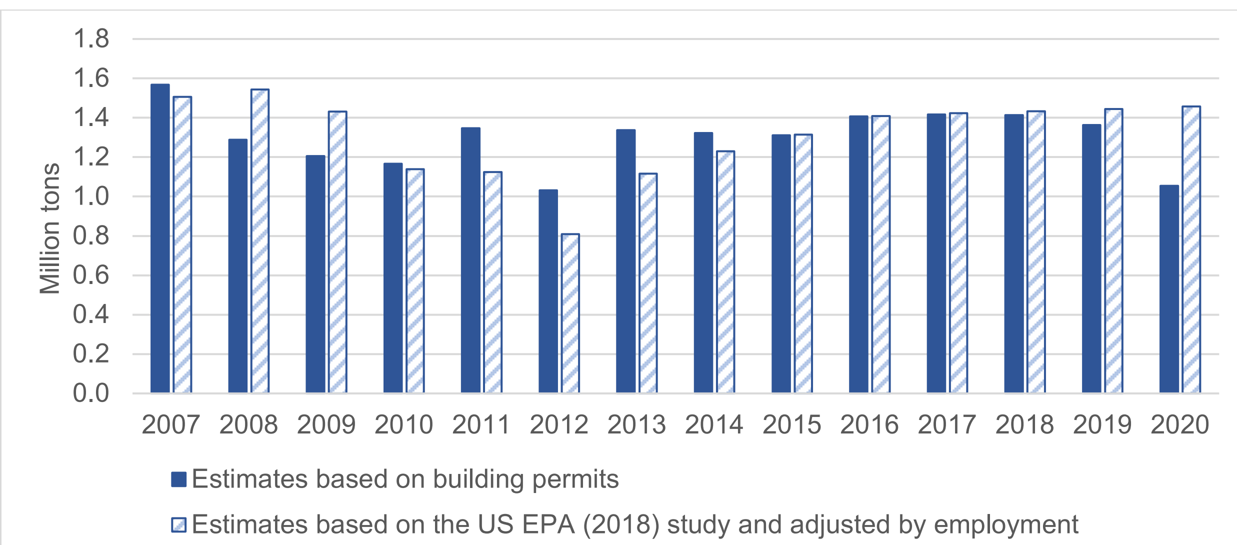
The other method builds upon the study by Weber, Kaplan, and Sokol (2009) that estimates the C&D waste volume based on the number of residential building permits (new construction, renovation, and demolition), and then estimates the non-residential building C&D waste based on the share of construction jobs for residential versus non-residential sectors. Building permit data are provided by the City of Chicago Data portal. As construction activities decreased (2007-2009), so did C&D waste generation. As noted by the Delta Institute (2019), construction activities recovered around 2012-2014. After the recovery period, C&D waste generation has remained at 1.31-1.42 million tons each year. As shown in Figure 16, results from two estimation methods are generally consistent. The biggest difference occurred in 2020, when the total number of permits decreased by 19.4% compared to 2019.

Figure 15 C&D Waste Composition (2010-2015)



Note: Data are provided by the Delta Institute and the City. Data aggregation and chart by the UIC team.

Figure 16 C&D Waste Volume from Buildings (2007-2020): Comparison of Two Estimation Methods



Note: This chart compares the estimation results in Figure 17 (based on building permits) to another method (based on the EPA 2018 study below and adjusted by employment). Modeling and chart by the UIC team.

4. Material-Specific Trend Analysis

Under data constraints, the numerical analysis in Section 3 reveals a limited amount of material-specific information. This section supplements the above volume analysis in two ways. Section 4.1 summarizes findings from the trending patterns of consumer expenditure; Section 4.2 reports on the literature review of policy and technology innovations and changes since 2010, as well as statistics reported at the national and regional levels.

By no means an exhaustive list, this review aims to reveal those evolutions in waste management system operation, technology, business models, relevant laws and policies between 2010 and 2020 that cannot be analyzed numerically of waste volumes due to data constraints. Special attention has been paid to possible factors or material trends that may not be fully captured by the single metric of total waste tonnage; for example, changes in consumer commodity purchase and waste disposal locations (grocery vs. restaurants), consumer purchase behaviors (online vs. retail), packaging materials (light weight and material substitution), and material recovery facilities that accept comingled or single-stream waste materials.

4.1 Changes in Consumer Expenditure

It is assumed that the changes in the MSW generation volume generally correlated with household expenditure on goods and services (US EPA, 2020). The US Bureau of Labor Statistics Consumer Expenditure Survey provides annual consumer expenditure data up to 2018. The Chicago metropolitan statistical areas (MSA) is the most granular geographic scale in the Survey. The project further adjusted the annual consumer expenditures to the 2010 US dollar using Consumer Price Index (CPI).

Analysis of the consumer expenditures (Table 2) reveals considerable increases in Chicagoan's expenditure on Alcoholic beverages, Food away from home, and Household furnishings may have contributed to increases in waste generation of glass (or other types of beverage containers), food scrap, and C&D waste/Household Hazardous Waste/White Goods, respectively. Meanwhile, decreases in consumer expenditure on Apparel and ensuing textile waste generation may have been cancelled off by the fast fashion trends.

4.2 Review of documented changes in material and waste management

A cross-sector literature review is conducted for each material class: C&D, organics, paper/cardboard, plastics/beverage containers, textiles, metal, glass, household hazardous waste (HHW), and white goods, as well as MSW in general. Tables 3-11 below summarizes both quantitative and qualitive information in terms of

(1) documented changes to waste generation rate or volume; (2) documented changes to landfill diversion rate or volume; (3) technology and product innovations impacting waste generation or recycling; and (4) policies implemented impacting Chicago since 2010. Pandemic related trends are differentiated from non-pandemic related trends, in separate columns.

Table 2 Chicago MSA Consumer Expenditure (2010 vs. 2018)

	2010	**2018**	**Pct Changes**
Alcoholic beverages	425	580	36.49%
Healthcare	3,793	4,862	28.20%
Housing - Household furnishings and equipment	1,538	1,857	20.75%
Personal care products and services	715	853	19.42%
Food away from home	2,825	3,340	18.24%
Housing - Household operations	1,204	1,291	7.29%
Reading	117	118	0.67%
Housing - Housekeeping supplies	671	673	0.37%
Food at home	4,355	4,352	-0.05%
Housing - Shelter	13,141	13,101	-0.30%
Education	1,682	1,629	-3.12%
Miscellaneous	781	714	-8.61%
Transportation	8,502	7,761	-8.72%
Housing - Utilities, fuels, and public services	3,975	3,524	-11.35%
Apparel and services	2,021	1,722	-14.75%
Entertainment	3,098	2,506	-19.10%
Tobacco products and smoking supplies	298	197	-33.92%
Total	49,136	49,081	-0.11%

Note: Original data from Consumer Expenditure Survey (Chicago MSA); expenditure data are CPI adjusted by the UIC team to the 2010 US Dollar.

This review focuses on evolving changes in MSW management in the Chicago area, and refers to existing references in urban regions (e.g., Illinois EPA Region 2) and national statistics. Due to time constraints, this project only focuses on the events that have documented impacts on the MSW system. Many other events that may have indirect or long-term impacts could not be included in the summary; for example, the anticipated institutional support from newly legislated Illinois Statewide Materials Management Advisory Committee in 2021 and the approval of the pharmaceutical rule in 2020.

Table 3 Municipal Solid Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated that the average per capita MSW generation rate (excluding C&D) was 4.4 lbs/day in 2010 and remained relatively stable until 2018, when it increased to 4.9 lbs/day. The increase, however, reflects a change in the US EPA's food waste measurement methodology (US EPA, 2020). • Illinois Region 2 reported a 4.9% increase (from 8.31 lbs/c/day to 8.72 lbs/c/day in MSW generation rate between 2008 and 2014 (compared to decreasing trends in other Illinois regions) (CDM Smith, 2015). • The City of Chicago generated 4.13 million tons of waste in 2020 compared to 4.02 million tons in 2010 (see earlier sections in this report for estimation methods and raw data references).	• The City of Chicago reported an increase in SF residential waste generation in 2020, compared to non-pandemic trending predictions. • In an EREF and NWRA survey (2020) of waste industry employees and affiliates, over two thirds of respondents reported changes of specific waste stream, including decreases from the commercial sector, with the largest increases coming from the residential sector. • Less waste was generated from schools and offices; more waste was generated from residences. One hauler reported an increase from 28 tons to 31 tons of collection every day, including more packaging materials from takeout food and online shopping (Porter and Holder, 2020).
Documented changes to landfill diversion rate or volume	• Nationally, the MSW recycling and composting rate plateaued at 34.0%-35.0% between 2010 and 2017, then dropped to 32.1% in 2018, which reflects a change in measurement methodology of organic waste (US EPA, 2020). • Statewide, Illinois EPA (IEPA) reported an increase in recovery/diversion rates of MSW from 19.1% in 2008 to 37.3% in 2014 (CDM Smith, 2015). • The City of Chicago reported various recycling rates of Blue Cart program across the six service regions in the City between 2014 and 2019. While some service regions showed relatively consistent performance over time, there was a general trend of declining rates (measured by material weight).	• The City of Chicago reported an increase in SF residential waste collected for recycling in 2020, compared to non-pandemic trending predictions. • Labor shortages and slowdowns were noted related to coronavirus (Porter and Holder, 2020).
Technology and product innovations impacting waste generation or recycling	• Automated material separation system was installed in the Chicago recycling facility (Carr, 2016). • Intelligent (optical) sorting equipment to facilitate contamination identification and efficient sorting was adopted at an MRF in Chicago in 2019 (Staub, 2020a).	• Intelligent (optical) sorting equipment to facilitate contamination identification and efficient sorting was adopted at an MRF in Chicago in 2019 (Staub, 2020a).
Policies implemented impacting Chicago since 2010	• The Chicago Blue Cart recycling program expanded to cover all SF homes/apartments/condominiums/townhomes with 4 or fewer units (about 600,000 households) in 2013. • The City of Chicago changed from a ward to grid-based collection system in 2013. • Chicago Blue Cart recycling went bagless (recyclables contained in bags are no longer accepted) starting 2016. • Chicago Recycling Ordinance passes in 2017. • Chicago community campaigns launch to boost resident participation in recycling and to reduce contamination in 2018.	

Table 4 Construction & Demolition Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Illinois EPA Region 2 reported a 38.1% increase, from 665.4 lbs/c/yr to 918.8 lbs/c/yr, in C&D waste generation rate between 2008 and 2014 (CDM Smith, 2015). • The number of building permits, which may directly impact the C&D waste generation volume, generally decreased between 2007 and 2012 (except in 2011) and then recovered after 2013 (City of Chicago Data portal, 2020). • Composition of material types being landfilled has changed; percentage of wood landfilled increased (Delta Institute, 2019). • Considerable increases in Chicago MSA household expenditure on household furnishings from 2010 to 2018 (US BLS, 2020) may have contributed to increases in C&D waste volume. • The City of Chicago reported that shares of C&D refuse and steel out of the total C&D waste decreased; the shares of asphalt, concrete, and wood increased between 2010 and 2015.	• No. of building permits in Chicago decreased in 2020 (City of Chicago Data Portal, 2020). • C&D volumes have dipped due to work stoppages and delays in some cases (Crunden, 2020). • Residential construction is steady; commercial is down (Karidis, 2020; Elder Demolition, 2020).
Documented changes to landfill diversion rate or volume	• Statewide, Illinois EPA reported an increase in C&D waste recovery/diversion rates from 5.9% in 2008 to 56.9% in 2014 (CDM Smith, 2015).	• Increases in home improvement projects but lack of recycling knowledge (Crunden, 2020).
Technology and product innovations impacting waste generation or recycling	• Technologies have facilitated costs savings in reclaiming C&D waste products (Shooshtarian et al., 2020). • Robotics and AI are deployed to assist with sorting and automate recycling in most commodities (Karidis, 2020).	• Increasing adoption of AI could be useful when construction crews must be socially distanced.
Policies implemented impacting Chicago since 2010	• Illinois SB 1807 passes, exempting C&D debris from franchise waste agreements (eff. 1/1/2018). • IEPA proposes rules for the use of clean construction or demolition debris (CCDD) and uncontaminated soil (US) as fill material, Pub. Act 96-1416 (eff. 7/30/2010).	

Table 5 Organic Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated increases in the generation volume of both food waste and yard trimmings between 2010 and 2017. • Nationally, the US EPA (2020) estimated 63.1 million tons of food waste were generated in 2018. The significant increase from 2017 (40.7 million tons) reflects a change of food waste measurement methodology/scope (US EPA, 2020). • Illinois EPA Region 2 reported a 6.7% increase, from 568.4 lb/c/yr to 606.4 lb/c/yr in Organic waste generation rate between 2008 and 2014 (CDM Smith, 2015). • Considerable increases in Chicago MSA household expenditure on food away from home from 2010 to 2018 (US BLS, 2020) may have contributed to increases in food scrap volume.	• Waste generation has shifted from commercial and institutional to residential settings (Gunders et al., 2020; Roe et al., 2020). • Chicago-area composters serving all sectors report mixed trends in food scrap generation, from –66% to +50% during the pandemic. A Chicago-area hauler notes an increase in yard clipping generation (Nelson, 2020). • The pandemic conditions caused massive disruptions to food system logistics and subsequently increases in food wastage (as well as shortage) (Ellison and Kalaitzandonakes, 2020). • The pandemic influenced many factors that are known to be related to food waste generation, including household size, employment status, and purchasing patterns (Roe et al., 2020).
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated increases in recycling/composting rates of food waste (from 2.7% to 6.3%) and yard trimming (57.5%-69.4%) between 2010 and 2017. • Nationally, the recycling/composting rate dropped from 33.8% in 2017 to 24.3% in 2018 due to a change of measurement methodology and scope. If all landfill diversion methods were considered, the diversion rate for organic waste was estimated at 38.2% in 2018 (US EPA, 2020). • Statewide, IEPA reported organic waste diversion/recovery rate increased from 14.0% in 2008 to 14.3% in 2014 (CDM Smith, 2015). • Illinois saw a significant increase in food scraps collected for composting between 2015 and 2017 (Johnston, 2019).	• Composting facilities in Minnesota and collection sites in New York City have closed or reduced capacity as a result of tightening municipal budgets and COVID protection protocols (Carleton, 2021; County Recycling, 2020).
Technology and product innovations impacting waste generation or recycling	• New food waste valorization technologies are being developed, including biofuel generation and energy production (Nayak & Bhushan, 2019). • Generation of bioplastics such as PLA increased (Castro-Aguirre et al., 2016).	
Policies implemented impacting Chicago since 2010	• Permit requirements for commercial food scrap composting in Illinois were reduced in 2009; food scraps became acceptable at previously permitted sites for yard trimmings only. • Permit requirements were lifted for urban farms and compost piles under 25 cubic yards in 2013. • Temporary and permanent drop-off sites are set up to allow household organics waste collection for composting (HB0437, 7/10/2015).	• Federal pandemic policies such as the Farmers to Families program and FDA's relaxed regulations for food labeling are likely to decrease waste and shift generation from commercial and industrial to the residential sector (Roe et al., 2020).

Table 6 Paper/cardboard Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated a 5.5% decrease in paper and paperboard generation volume, from 71.3 million tons to 67.4 million tons, between 2010 and 2018. • Illinois EPA Region 2 reported a 10.5% decrease in paper waste generation rate, from 886.2 lbs/c/yr to 793.2 lbs/c/yr, between 2008 and 2014 (CDM Smith, 2015).	• Greater decreases in high-quality paper scrap from commercial and office locations than increases from home offices in Minnesota) (Paben, 2020). • Higher-grade printing and writing paper generation decreased (Staub, 2020b).
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated increases in paper recycling rates from 62.5% in 2010 to 68.2% in 2018; otherwise, it was either landfilled or combusted. • Statewide, IEPA reported paper waste diversion/recovery rate increased from 33.3% in 2008 to 43.5% in 2014 (CDM Smith, 2015) • OCC recovery rates dropped in 2017 (partially due to Chinese import restrictions), recovered after finding alternative destination regions, and then dropped again when waste import restrictions became generally more stringent globally (American Forest & Paper Association, 2020).	• Increases in OCC generation from residents do not automatically boost the OCC recycling rate during the pandemic when household participation rates for OCC recovery are much lower than that from commercial sectors (Staub, 2020b). • The recycled newsprint market is diminishing (Staub, 2020b).
Technology and product innovations impacting waste generation or recycling	• Recycled newsprint market is diminishing (Staub, 2020b). • Increases in Old Corrugated Containers (OCC) generation is driven by the e-commerce market (Staub, 2020b).	• The pandemic accelerated the decreasing trend of the recycled newsprint market (Staub, 2020b).
Policies implemented impacting Chicago since 2010	.	.

Table 7 Plastic Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated a 13.6% increase in plastics waste generation, from 31.4 million tons in 2010 to 35.7 million tons in 2018. • Illinois EPA Region 2 reported a 3.1% decrease in plastic waste generation rate, from 339.0 lbs/c/yr to 328.5 lbs/c/yr between 2008 and 2014 (CDM Smith, 2015).	• Increases in generation from personal protective equipment (PPE) and healthcare, including plastic lining and components (Tripathi et al., 2020; Vanapalli et al., 2021). • Increases in single use plastics associated with higher demand for restaurant takeout food (utensils and packaging) and PPE (Knowles, Zimmermann, and Piston, 2020). • Increased generation of food packaging and grocery bags (Vanapalli et al., 2021). • "The International Solid Waste Association estimates consumption of single-use plastic may have grown 250% to 300% in America since the coronavirus pandemic began." (Knowles, Zimmermann, and Piston, 2020). • These trends may be partially offset by decreased generation from large events, travel, and institutional settings during lockdowns (Tripathi et al., 2020).
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated an increase in the plastics recycling rate, from 8.0% in 2010 to 8.7% in 2018. • Statewide, IEPA reported the plastics recycling rate increased from 6.2% in 2008 to 8.1% in 2014 (CDM Smith, 2015). • Uncertain markets for post-consumer plastics have led to some collected recyclables being landfilled in Illinois and minor service interruptions in the Chicago region (Rosengren et al., 2019).	• Several US states have documented decreases in plastic recycling collections during lockdowns (Vanapalli et al., 2021).
Technology and product innovations impacting waste generation or recycling	• Light-weighting of plastic bottles has offset an increase in plastic bottle use (Association of Plastic Recyclers, 2019). • Improvements to at least one MRF lead to increased recycling capacity regionally (Carr, 2016).	
Policies implemented impacting Chicago since 2010	• Plastics grocery bags are banned from Blue Cart program in 2017 (Tom Vujovic at Waste Management, interviewed by NPR [Eng, 2019]) • Plastic bag fee expected to cause a 27.7% decrease in plastic bag generation from grocery stores (Homonoff et al., 2018).	

Table 8 Textile Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated a 28.8% increase in textile waste generation volume, from 13.2 million tons in 2010 to 17.0 million tons in 2018. • Illinois EPA region 2 reported a 30.6% decrease in textile waste generation rate, from 178.5 lbs/c/yr in 2008 to 123.8 lbs/c/yr in 2014 (CDM Smith, 2015).	• Usage of masks increased.
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated an increase in recycled textile volume (2.1 million tons to 2.5 million tons) but a decrease in textile recycling rate (15.5% to 14.7%) between 2010 and 2018. • Statewide, IEPA reported textile recovery/diversion rate increased from 2.0% in 2008 to 19.0% in 2014 (CDM Smith, 2015).	
Technology and product innovations impacting waste generation or recycling	• Shift towards sustainability, along with eco-friendly initiatives by manufacturers, is expected to boost the recycled textile market growth (The Insight Partner, 2021). • Increasing demand for antimicrobial textiles in recent years (Ardusso, 2021) • Increasing use of sustainable and commercial chemicals to recover cotton from waste textile (Yousef, 2019). • Hyperspectral near infrared imaging is anticipated to automate textile characterization and recycling (Mäkelä, 2020). • Increase of fast fashion, synthetic fabrics that are harder to recycle and also pollute as they break down (Niinimäki et al., 2020).	• Increased use of textile fibers impregnated with Ag and Cu nanoparticles for manufacturing face masks and commercial products (Ardusso, 2021)
Policies implemented impacting Chicago since 2010	• Clothes and linens are not accepted by the Chicago Blue Cart program.	• Mask mandates are enacted (May 2020). • CDC recommends double masking (2/10/2021).

Table 9 Metal Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated a 14.0% increase in total metal waste generation volume, from 22.5 million tons in 2010 to 25.6 million tons in 2018. • Illinois EPA Region 2 reported a 10.9% decrease, from 138.2 lbs/c/yr in 2018 to 123.1 lbs/c/yr in 2014 in Metal waste generation rate (CDM Smith, 2015).	• Higher levels of aluminum identified in the stream (Paben, 2020).
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated an increase in recycled metal volume (7.9 million tons to 8.7 million tons) but a decrease in metal recycling rate (35.3% to 34.1%) between 2010 and 2018. • Statewide, IEPA reported metal recovery/diversion rates increased from 16.6% to 57.4% between 2008 and 2014 (CDM Smith, 2015).	• Demand from manufacturing and construction industries for scrap metals is expected to decline (IBISWorld, 2020).
Technology and product innovations impacting waste generation or recycling	• Rapid technology advances have transformed waste electrical and electronic equipment (WEEE) processing from simple disassembly, classification, and sorting to high value-added utilization technologies (Zhang and Xu, 2016).	
Policies implemented impacting Chicago since 2010		

Table 10 Glass Waste Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Nationally, the US EPA (2020) estimated a 6.3% increase, from 11.5 million tons to 12.3 million tons, in glass generation volume between 2010 and 2018. • Illinois EPA Region 2 reported a .2% decrease, from 86.2 lbs/c/yr to 86.0 lbs/c/yr, in glass waste generation rate between 2008 and 2014 (CDM Smith, 2015). • Chicago MSA household expenditure on Alcoholic Beverages saw the fastest growth among all expenditure categories from 2010 to 2018 (US BLS, 2020), which may have contributed to increases in glass waste volume.	• Potentially reduced generation from shuttered bars and restaurants (Kummer, 2020).
Documented changes to landfill diversion rate or volume	• Nationally, the US EPA (2020) estimated a decrease in recycled glass volume (3.13 million tons to 3.06 million tons) and a decrease in glass recycling rate (27.2% to 25.0%) between 2010 and 2018. • This decreasing trend is likely driven by cities and counties eliminating glass from curbside recycling programs to enhance cost-effectiveness (Keller, 2018; Ng, 2015; Pyzyk, 2021), which has not occurred to a significant extent in the Chicago region (Pyzyk, 2021). • Statewide, IEPA reported glass diversion rate increased from 21.7% in 2008 to 25.3% in 2014 (CDM Smith, 2015).	• O-I glass estimates a reduction of recycled glass market of 20-62% as the combined result of pandemic-related reductions in generation and recycling due in several Northeast markets (Kummer, 2020).
Technology and product innovations impacting waste generation or recycling	• Glass bottles are 40% lighter than they were 30 years ago (Rue, 2018). • Recent trends in craft beer have led to several new programs producing, collecting, and refilling glass bottles. These refillable bottles can be heavier than single-use glass bottles (Gribbins, 2018). • At least one Chicago-area MRF, RMC in Chicago Ridge, has added capacity for cleaning and sorting glass in single-stream recycling (Keller, 2018).	
Policies implemented impacting Chicago since 2010	• In single-stream recycling systems, such as Chicago's, broken glass may also contaminate more profitable commodity streams such as cardboard and paper (Flower, 2015).	• Chicago and recycling partners did not make large changes to recycling programs as a result of the pandemic, such as program and enforcement suspensions seen in many bottle deposit states (Pyzyk, 2021; Tripathi et al., 2020).

Table 11 Household Hazardous Waste (HHW) and White Goods Trends

	Non-pandemic related trends 2010-2020	Pandemic related trends 2020
Documented changes to waste generation rate or volume	• Illinois EPA Region 2 reported a 6.6% decrease, from 28.8 lbs/c/yr in 2008 to 26.9 lbs/c/yr in 2014 in HHW generation rate (CDM Smith, 2015).	• E-waste volume increased from 348,812 lbs to 350,188 lbs in 2020 (City of Chicago, 2021). • Increases in residential drop-off volumes possibly related to home improvement or cleaning (Nemo, 2020). • City collection was closed for about three months due to COVID-19 (City of Chicago, 2021). • Hazardous chemical totals decreased from 138,074 lbs in 2019 to 125,546 lbs; pharmaceutical totals decreased from 12,542 lbs to 7983 lbs in 2020 (City of Chicago, 2021).
Documented changes to recycling rate or volume	• Statewide, IEPA reported HHW recovery/diversion rates decreased from 65.2% in 2008 to 62.3% in 2014 (CDM Smith, 2015). • The e-waste market is anticipated to reach $40 billion by 2025 (Adroit Market Research, 2020).	
Technology and product innovations impacting waste generation or recycling	• Light weighting trends of products discourage manufacturers from recycling, given the Illinois legislation is based on the weight of electronics sold (Ruppenthal, 2017). • Kuusakoski Glass and PDC launched a program that processed and treated CRT glass as alternative daily cover (ADC) at the PDC landfill (Peoria, IL) in 2014. In 2015, they adopted a storage-cell method as an additional method. In 2020, the disposition program was phased out (Leif, 2019) • Artificial intelligence-based MCA and EPR is a reasonable approach to address the increasing problems with e-wastes (Chen, 2021). • New and emerging technologies will continue to accelerate obsolescence and create new waste streams (Shittu et al., 2021)	• Demand for electronics was induced by the pandemic conditions (Yu, Yu, and Tan, 2020). • Demand for used electronics increased (Paben, 2021).
Policies implemented impacting Chicago since 2010	• Illinois Electronics Products Recycling and Reuse Act (EPRRA) (eff. 1/1/2012). • Illinois Consumer Electronics Recycling Act (CERA) signed on August 25, 2017 and replaced EPRRA on 1/1/2019. • Illinois Pollution Control Board adopted U.S EPA's RCRA Subpart P amendments in September 2020, which change the standards for entities that generate or manage hazardous waste pharmaceuticals. • Landfill ban of white goods without the removal of components, 7/1/1994.	

5. Key Findings and Recommendations

Table 12 summarizes the key findings and recommendations based on both qualitative and quantitative analysis of national, regional, and City reported data, academic research, industry surveys and reports, and well-regarded industry magazines as well as major news outlets.

Clearly there are some cross-sector trends and issues in the last decade; for example, the critical role of residential awareness of and participation in recycling, the confounding factors of light-weighting trends of materials, varying levels of recycling performance across Chicago neighborhoods and varying quality of data reporting from service providers, and the side-effects of single-stream recycling on contamination, as well as multi-facet impacts of pandemic conditions on material and waste management. Additional studies are needed to better understand the trends, to identify the priorities of waste diversion performance, and to better inform proactive planning and policy making. All these call for more rigorous efforts for waste data collection, data reporting enforcement, and data sharing.

Table 12 Key Findings and Recommendations

Key Findings	Recommendations
In 2020, the City of Chicago generated an estimated amount of 4.13 million tons of waste from residences, institutional/ commercial/industrial (ICI) sectors; and building construction and demolition (C&D) activities. Overall, there is an increase in waste generation in the last decade. Yearly fluctuations of waste generation volume seem to respond to economic conditions.	• Caution should be given when interpreting data under pandemic conditions or using 2020 data as a benchmark for decennial planning. • Tonnage is not and should not be used as the single metric to measure material and waste management program performance.
The availability and quality of waste stream data vary by generation activity (sector) and by service provider.	• Consistency and enforcement of data reporting is needed.
Higher volume of refuse and commodities were collected by the Chicago from single-family (SF) residential homes in 2020, compared to 2019 and predicated value in 2020 from time-series modeling.	• While the locations of waste generation have shifted towards residences during pandemic conditions, education programs for City residents can be particularly important.
Multi-family (MF) residential units in Chicago steadily increased between 2010 and 2020, so did residential waste.	• Given many documented challenges of MF residential recycling nationwide (e.g., NYC Bureau of Waste Prevention, Reuse and Recycling, 2001), additional resources and educational programs may be needed to advance residential recycling goals in Chicago.
On average, each Chicago resident generates a little over 3 pounds (lbs) of waste per day at home, or a little under 3,000 lbs of waste per year for each Chicago household. Compared to other peer cities and regions (e.g., NYC and California), residential waste generation rates in Chicago are higher (NYC Department of Sanitation, 2018; CalRecycle, 2021).	• There are potentials for source reduction from Chicago residences.
After the Chicago Blue/Black Cart Program expanded from limited coverage to city-wide implementation, commodity volume collected per household for recycling decreased, which suggests the increases in recycling participation did not keep up with the City's recycling program expansion. The decreasing trend of recycling performance turned around in 2018, when the City launched community campaigns to boost residents' participation in recycling and to reduce contamination.	• Community education programs matter.

Table 12: Key Findings and Recommendations (continued, 2 of 3)

Key Findings	Recommendations
Blue Cart program performance varies across the six service regions in the City.	• Additional data and further analysis (e.g., demographics, public vs. private operations, market development, macroeconomic conditions) are needed to explore cost-effective and region-specific strategies to improve recycling performance.
About 522,510 tons of organic waste are estimated to be generated in Chicago every year, including 245,260 tons from SF residential, 81,250 tons from MF residential, and 196,000 tons from ICI sectors. Implementing source separation of 75% of organic waste from SF homes would boost landfill diversion rate by 18.6%.	• Implementing organic waste diversion programs has great potential to increase the diversion rates in Chicago.
Total employment in Chicago increased 2010-2018; employment in the Restaurant and Food industry had the fastest growth, by 28.29%. Consumer expenditure on Food away from Home increased 18.24%. Reported increases in food waste generation in the Illinois outpaced diversion efforts (CDM Smith, 2015).	• Increasing food waste volume and possible changes of generation location requires further analysis and proactive planning for food scrap as a target stream in Chicago.
Among different material classes generated from ICI sectors, Glass increased the largest, by 22.44% (from 37,389 tons to 45,779 tons).	• Increases in glass waste (despite the light-weight trend) in Chicago, the heavy weight of glass, and possible contamination of broken glass for profitable commodity items in the single-stream recycling suggests that glass waste should be another target for waste diversion program in Chicago.
The composition of C&D waste in the City changed over time. Between 2010 and 2015, the shares of C&D refuse and steel out of the total C&D waste decreased; the shares of asphalt, concrete, and wood increased. Information after 2015 is not available or consistent for a comparison.	• Enforcement is needed for waste data reporting. Consistency and clarity in the reporting forms are important.
Building C&D waste generation in Chicago is estimated to be at 1.31-1.42 million tons annually. Additional information is needed for a reliable estimate for C&D waste from other activities (e.g., road and bridge construction and maintenance).	• Besides building C&D waste, more specifics are needed for other types of C&D waste in the Chicago city ordinance.

Table 12: Key Findings and Recommendations (Continued, 3 of 3)

Key Findings	Recommendations
Fast fashion and synthetic fabrics have presented challenges for textile waste management. Uses and discards of masks have significantly increased during pandemic conditions. Statewide, Illinois (CDM Smith, 2015) saw increases in textile recovery/diversion rate increased from 2.0% in 2008 to 19.0% in 2014. Clothes and lines are not accepted by the Chicago Blue Cart program.	• New programs for textile reuse and diversion may be needed to address the lagging performance of textile waste management.
The amount of MSW generated per dollar spent is decreasing (US EPA, 2020). Light-weighting trends of electronic products discourage manufacturers from recycling, given that the Illinois legislation is based on the weight of electronics sold (Ruppenthal, 2017). Light-weighting of bottles has offset an increase in bottle uses (Association of Plastics Recyclers, 2019; Rue, 2018).	• Light-weighting material trends present an important confounding factor for the traditional approach of measuring material and waste management by weight (tonnage) only. Additional studies are needed to assess the impacts of light-weighting trends.
Nationwide, some materials showed opposite trends of recycled volume and recycling rates. For example, the recycled volume of metal and textile increased but the recycling rates dropped in the last decade (US EPA, 2020).	• Multiple metrics (instead of one single metric of waste tonnage or recycling rate) should be analyzed. Environmental life cycle impacts and socioeconomic impacts should be also considered on a case-by-case basis.
Pandemic conditions changed not only the waste volume but also composition and location. Documented increases in waste from home renovation projects and packaging materials from takeout food and online shopping, but lack of recycling knowledge from residents (Cruden, 2020; Porter and Holder, 2020).	• Additional efforts and resources are needed to support residential recycling during pandemic conditions.

Note: All waste volumes are in US short tons.

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Appendix: Definitions of Waste Stream in Chicago 2010 Study

The 2020 Chicago waste generation and characterization studies uses the 2010 Chicago waste study as the baseline and has adopted its definitions, material, and sector classification systems. The Chicago Waste Characterization Study (CDM, 2010b, ES-1 to ES-3) provides the following description. Further, it documents that the Chicago Department of Streets and Sanitation (DSS) collects waste from residences (typically single family homes/ apartments/condominiums/ townhomes with 4 or fewer units), and the private waste haulers collect waste from Institutional/Commercial/Industrial (ICI) sectors, multi-family residential, and C&D waste. It also clarifies that haulers do not distinguish between residential and commercial buildings for waste collection.

- *Residential – waste collected by private haulers from multi-family residences (typically apartment buildings and condominiums) and waste collected by the Department of Streets and Sanitation (DSS) from residences (typically single family homes/ apartments/condominiums/ townhomes with 4 or fewer units). This waste is primarily collected in packer trucks (e.g., side-loading or rear loading vehicles).*

- *Institutional/Commercial/Industrial (ICI)-Includes waste generated by industrial and commercial businesses and institutions;*

    - *Commercial and Institutional – waste generated by businesses and government/education institutions. This waste is collected in a variety of vehicles including loose and compactor drop boxes, and front-end loading trucks. Small commercial facilities are collected in packer trucks.*

    - *Industrial – waste generated by industrial activity, such as that of primary and fabricated manufacturing facilities, and mills. Unlike regular municipal waste that is primarily food, packaging and disposed products, industrial waste is the material disposed from the production of the specific commercial and consumer goods being manufactured at that location.*

    - *The ICI waste sector was further divided into the following five industry groups, which make up approximately 76% of the ICI waste stream:*

        o Restaurants, bars, food stores, food manufacturing;
        o Financial, insurance, real estate, legal, professional, consulting;
        o Manufacturing (except food);
        o Government, schools, higher education, post office; and
        o Wholesale.

- *C&D – waste generated from new construction, renovation activities, or demolition. This waste is collected in vehicles such as dump trucks, loose roll-off boxes, and end dump vehicles. This includes clean construction or demolition debris (CCDD) includes the following uncontaminated materials (415 ILCS 5/3.160(b)): broken concrete without protruding metal bars; bricks; rock; stone; reclaimed asphalt pavement; and dirt or sand generated from construction or demolition activities and diverted C&D materials.*