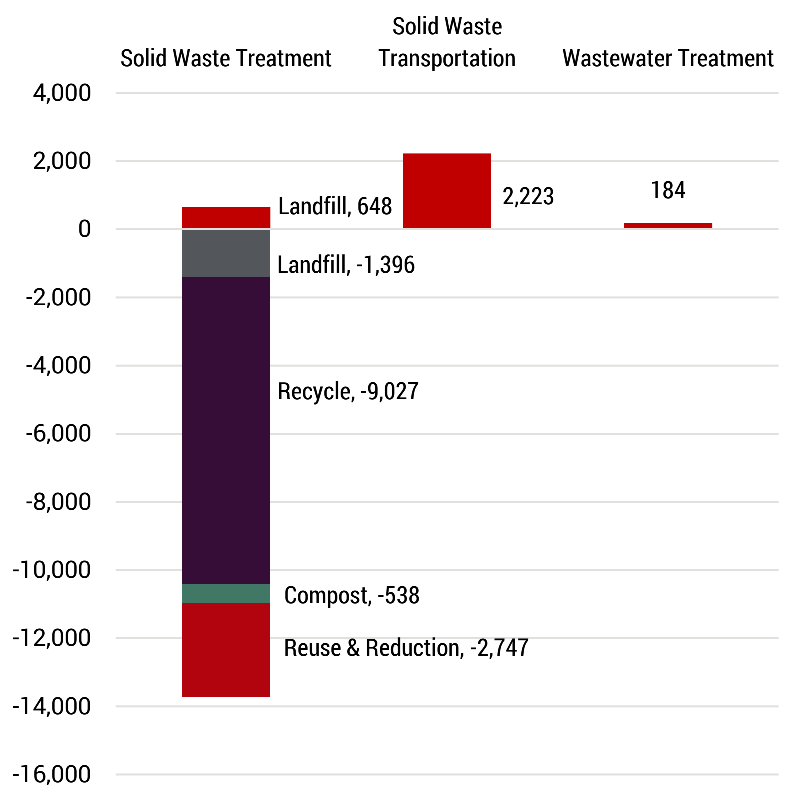
Scope 3 Emissions from Waste

Category Overview: Definition, Boundary, Methodology, and Preliminary Results

Executive Summary



Scope 3 emissions from waste are calculated on a regular basis for Stanford University by the Scope 3 Emissions Program in Business Affairs. This paper details the boundary and methodology for developing baseline waste emissions for calendar year 2019. More information on the Scope 3 Emissions Program and baseline calculations in other scope 3 emissions categories can be found in the Stanford University CY2019 Scope 3 Emissions Program Description & Inventory.

Scope 3 emissions from waste derive from greenhouse gases emitted through the decomposition of organic (carbon-containing) materials. However, these emissions can also be avoided through common waste practices, such reducing, reusing, recycling, and composting refuse. These practices also have other positive impacts on greenhouse gas emissions, such as avoided emissions from extraction of raw materials, or increasing soil carbon capture. Together, Stanford considers the net emissions effects of these practices to be its scope 3 emissions from waste.

Specifically, this category includes net emissions from the disposal and treatment of solid waste and wastewater. Emissions from solid waste transportation are also included. Treatments for solid waste include landfilling, recycling, composting, reusing, or reducing waste goods. The respective positive and negative emissions from each of these activities are shown in Figure 1 to the right.

Considering the net emissions effects of these activities at Stanford, the university's scope 3 emissions from waste in calendar year 2019 were -10,653 MT CO2e. The negative value indicates that Stanford's waste disposal methods are less detrimental to the planet than they otherwise could be—if for example, all these items were sent to a traditional landfill with no methane recovery technology. This effect will only continue as Stanford diverts more and more waste away from traditional landfills to reach its zero waste goal.

For perspective, the absolute value of waste-related scope 3 emissions is equal to 5% of Stanford's peak combined scope 1 & 2 emissions of 198,349 MTCO2e in 2011.

Stanford has one of the longest running university waste diversion programs in the country, with roots going back to the 1970s when students first established a recycling program for the campus. In 2019, Stanford's diversion rate (percent of total waste diverted away from the landfill) was 66%, and the university has a goal of achieving zero waste—defined as 90% diversion from the landfill—by 2030. The robust reuse, waste reduction, recycling and composting programs employed at the university today are award winning and, in many cases, innovative.

The emissions from waste on campus are based on the weight of material disposed of in each stream by material type, as reported by the university's waste haulers and reuse vendors. This data was put into two third party tools and one internal model. In turn, each of these tools was used to calculate scope 3 emissions from waste. The inputs and outputs of these tools were compared to determine the tool most relevant to Stanford's waste profile. Based on the winning tool—the internal model—calculation of emissions in this category involves the following steps and data sources:

- Gathering and aggregation of waste weight data by stream (performed by the Office of Sustainability to calculate annual waste diversion metrics)
- Estimation of emissions from solid waste reduced, reused, recycled, composted, and landfilled by material type based on the Waste Reduction Model (WARM) developed by the U.S. Environmental Protection Agency (EPA)
- Integration of the effects of landfill gas recovery and electric generation. In other words, the landfill where Stanford sends its waste captures methane emitted from the landfill, and this methane is used to generate electricity. Note that this results in net negative emissions from landfilling because of the avoided emissions from burning fossil fuels to produce electricity.
- Calculation of emissions from transportation of solid waste using data from the university's waste haulers on the number of trips between campus and the disposal facilities and exact distance traveled. This calculation also encompasses estimates for emissions from shipping recyclables overseas.
- Estimation of emissions from wastewater treated aerobically and anaerobically

As shown in Figure 1, recycling activities have by far the most positive environmental impact of all waste-related practices. Avoided emissions from recycling account for 70% of Stanford's total avoided emissions from waste, even though approximately the same amount of Stanford's waste is recycled each year as is composted (slightly over 8,000 tons per year are disposed of in each stream). Because recycled goods comprise such a large portion of Stanford's waste footprint, accurate and transparent tracking of all recycled goods at Stanford will be imperative to developing meaningful annual waste emissions estimates.

While Stanford's current recycling programs are highly effective, 26% of Stanford's landfilled waste material is recyclable, and diverting these recyclables out of the landfill stream should take priority due to their highest impact on emissions. Source reduction and reuse programs also have high potential for reducing emissions. The Stanford Zero Waste plan already integrates measures like these, and the Scope 3 Emissions Program will continue to communicate with those implementing the plan so that emissions savings are considered during prioritization of Zero Waste Plan measures.

Background

Stanford's waste reduction, recycling, composting, and solid waste program serves all academic and athletic areas, Residential & Dining Enterprises (R&DE), Faculty Staff Housing, Stanford University School of Medicine, SLAC National Accelerator Laboratory, and all associated construction sites. Stanford's waste hauler also works with campus elementary schools and preschools on zero waste outreach, trainings, and a compost program to collect food scraps and paper towels. Land, Building & Real Estate (LBRE) manages the waste hauling contract.

Through Stanford's advanced waste programs, vast infrastructure is available across the main campus for recycling, composting, landfill, and reuse. This infrastructure includes:

- Dual stream recycling in academic buildings, where paper is recycled in one bin and plastics/metal/glass are recycled in a separate bin
- Single stream recycling in the majority of R&DE facilities, where paper, cardboard, plastic, metal and glass are all recycled in the same bin
- Central compost bins in some buildings
- Free, personal compost bins available to any interested staff member or student to facilitate composting in their office, room, or student apartment
- Custom waste management programs in R&DE, DAPER, and many lab buildings
- Desk-side landfill and paper recycling bins in some locations. These are currently being phased out in support of centralized waste stations
- Construction and demolition waste dumpsters and hauling services
- Large electronic equipment collection and resale by the Property Management Office, a division within the Office of Research Administration. Equipment that cannot be resold is recycled via a third-party vendor
- Small electronic equipment collection by Environmental Health & Safety at over 125 locations across campus. This equipment is refurbished or recycled via a third-party vendor
- Reuse efforts through the Property Management Office, including:
    - The Reuse website, Stanford's online mechanism for staff and faculty to advertise usable items they no longer need and are willing to transfer to another department
    - The Furniture Reutilization Program, which allows departments to easily dispose of and obtain furniture at little or no cost. The program maintains warehousing space in Redwood City, where furniture from one department is stored until it can be used by another department
- Reuse efforts through R&DE, including:
    - Regular leftover food donation from dining halls
    - The annual Give & Go moveout program that facilitates over 80 tons of donations as students move out of dorms each June
- Conversion of food waste from Stanford's dining halls into animal feed

The Stanford Redwood City campus has more homogenous needs; single stream recycling, compost and landfill bins are offered at central waste stations throughout all buildings. Waste at the Stanford Redwood City campus is serviced by the municipal waste hauler in Redwood City. The waste hauling contract in Redwood City is managed by the Stanford Redwood City Operations team.

Once collected by a waste hauler, the university's waste is then processed in distinct ways:

- Recyclables are sent to a Material Recovery Facility (MRF), which sort the recyclables into discreet material types and ship them to customers who utilize the recyclables in manufacturing new items. As part of this process, some residual waste—or material that cannot be recycled but was found in the recycling stream—is sorted out and landfilled. While this is a small portion of Stanford's waste, it is not accounted for in the emissions analysis detailed below. Another common issue in waste management is whether the recyclables sold are actually being recycled into new goods. To address this, **Stanford receives reports from its MRF of what ports its recyclables are shipped to and the end product**

they are used to create. Emissions associated with transportation—both to the MRF and from the MRF to overseas manufacturers—are included in the emissions analysis detailed below.
- Compostables are sent to a commercial composting facility.
- Landfill materials are sent to a landfill that utilizes methane recovery for electricity generation, as described in the Category Definition section.

In 2017, the university began to develop a zero waste feasibility study, which included in-depth analysis and planning to provide more detailed understanding of its waste streams, develop strategies to further reduce overall waste generation, increase diversion (material sent to recycling or composting instead of landfill), and work toward the ultimate goal of zero waste. These efforts synergistically aligned with Stanford's Long Range Planning process, which culminated with an official target to achieve zero waste by 2030, announced in May 2018. The Office of Sustainability created a detailed planning model to collect and analyze the data associated with Stanford's waste portfolio and propose solutions toward reaching zero waste. The planning included developing an extensive model, conducting a detailed waste characterization, and utilizing third-party peer reviews. This planning process spanned the course of more than two years, and involved a multi-step, data-driven effort to systematically outline a path to zero waste, described in more detail in the university's Zero Waste Plan.

Category Definition

Scope 3 emissions from waste are defined by the Greenhouse Gas Protocol as emissions from the disposal and treatment of all streams of waste generated due to the university's operations, including treatment of both solid waste and wastewater.[1] The Greenhouse Gas Protocol lists emissions from transportation of waste as optional for inclusion. Below are definitions of each component of this stream.

- **Solid waste** refers to all garbage and refuse. At Stanford, this means any item that ends up in the landfill, recycling, or compost waste streams or is reused or source reduced.
- **Solid waste treatment** refers to any method used to change the physical, chemical or biological character or composition of solid waste. At Stanford, this includes:
    - **Landfill:** disposal of waste in a man-made landfill. This results in greenhouse gas emissions (primarily methane) from the decomposition of any organic material in the landfill.
    - **Landfill Gas Recovery:** As municipal solid waste decomposes in the landfill, its contents are decomposed by microorganisms that perform aerobic and anaerobic decomposition. Aerobic decomposition occurs in the presence of oxygen and releases greenhouse gases. Anaerobic decomposition occurs in the absence of oxygen – such as in a wet environment, and/or when

Internal Review Process

Internal Approvers:

- **Julie Muir**, Waste Systems Program Manager, Office of Sustainability
- **Kristin Parineh**, Sustainability & Utility Manager, Residential & Dining Enterprises
- **Sophie Egan**, Director of Stanford Food Institute and Sustainable Food Systems, Residential & Dining Enterprises

Internal Collaborators:

- Office of Sustainability
- **Sarah Saboorian**, Undergraduate student

[1] Greenhouse Gas Protocol. "Technical Guidance for Calculating Scope 3 Emissions." World Resource Institute. 2013. https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf

the microorganisms consume all of the oxygen available – and this process produces methane, a more potent greenhouse gas than CO2. Some landfills have technology designed to harvest the methane released by the decomposing waste, and either burn it (called "flaring") to produce carbon dioxide, which has a lower greenhouse gas effect than methane, or burn it for generation of electricity. Burning methane for electricity is considered the least emissive option because it replaces the burning of fossil fuels. This process is referred to throughout this paper as "methane recovery for electricity generation."

  - **Recycling**: melting or otherwise treating the product to recycle it into another product. This results in greenhouse gas emissions that occur during the process of transforming the waste product into a new product but also avoids emissions associated with extraction of new material that otherwise would have been used to create the new product.
  - **Compost**: decomposition of organic waste in a compost pile. This results in greenhouse gas emissions from the decomposition of organic material but also improves soil carbon capture when finished compost is applied to soil, resulting in a net positive impact.
  - **Reuse:** If goods are reused that otherwise would have been disposed of, emissions are avoided that would have been generated from the disposal of that material. Emissions are also avoided from extraction of new material that otherwise would have been used to create the new product. Stanford has many programs that promote reuse across campus.
  - **Source Reduction**: If goods are not purchased at all that otherwise would have been purchased and disposed of, emissions are avoided form the disposal of that material and the extraction of new material that would have been used to create the product. Stanford has many programs that promote source reduction across campus.
- **Solid waste transport**: Trucks transport waste in all streams from Stanford facilities to waste disposal facilities. Landfilled waste goes to landfills; recyclables go to Material Recovery Facilities (MRFs) that sort the materials, sell them, and transport the sold materials to a new destination for them to be recycled (this portion often involves shipping the recyclables overseas); compost goes to commercial compost facilities and the finished compost is then sold and transported to its final destination. Emissions in this category are influenced by truck age, size and fuel efficiency, fuel type, distance to destination, route efficiency, tons of material transported per trip, and frequency of trips.
- **Wastewater treatment:**
  - Aerobic: a treatment process in which microbes break down organic matter in an oxygen rich environment, resulting in carbon dioxide, water, and other biomass as byproducts. The resulting biomass becomes sludge which is disposed of as hazardous waste.
  - Anaerobic: a treatment process in which microbes break down organic matter in the absence of oxygen, resulting in methane, carbon dioxide, and other biomass. There is less biomass/sludge produced through this process than through aerobic digestion. Additionally, the methane can be captured and used for energy, resulting in lower net greenhouse gas emissions than aerobic digestion.

Category Boundary

Physical Boundary

The physical boundary for this category includes all areas serviced under the university's waste hauling contracts for the main campus (including SLAC, and Faculty Staff Housing residential areas adjacent to it) and for the Stanford Redwood City Campus. The boundary does not currently include Stanford's other satellite properties, such as Hopkins Marine Station. These could be added to the boundary in the future if data is available from the respective waste haulers.

Waste Stream & Life Cycle Boundary

As with other scope 3 categories, Scope 3 Emissions Program staff have defined a robust and holistic boundary for Waste that also prioritizes alignment with existing zero waste programs and inclusion of the positive effects of all activities to which Stanford intentionally devotes resources. To that end, program staff (in partnership with the collaborators and approvers listed above) have made the following decisions that deviate from official guidance from the GHG Protocol:

- Inclusion of all life cycle emissions from products disposed of, including avoided emissions
- Inclusion of avoided emissions from source reduction and reuse programs

We believe that accounting for the impacts across the full life cycle of the products disposed of at Stanford is the most holistic way to understand the effects of Stanford's waste-related activities. Specifically, this means we have made an intentional decision to account for the avoided emissions from recycling, composting, reusing, and reducing waste, as well as from landfilling goods in a landfill with methane recovery and electricity generation. The availability of credible, negative emissions factors in the EPA's WARM tool bolstered this decision.

On the other hand, this philosophy differs from the guidance put forth by the GHG Protocol, which suggests that only positive emissions should be reported in this category. Most ESG reporting entities have adopted this guidance, so if Stanford were to report our emissions through any of these channels, we would be required to follow a different methodology. In practice, this means only calculating the operational emissions associated with 1) hauling emissions from landfilling and 2) the processes of composting and recycling, such as operating the facilities that perform composting and recycling. This approach does not reflect the benefits of landfill methane recovery for electricity generation, and the longer-term emissions impacts from composting and recycling. Exclusion of this practice has a significant impact on landfill emissions (in the realm of thousands of MTCO2e). In our view, this approach does not consider Stanford's waste treatment practices comprehensively or realistically.

The specific inclusion of the effects of reuse and reduction represents another deviation from formal reporting guidelines. Despite this, we have intentionally included them to align with Stanford's existing waste management philosophy, which follows the waste hierarchy published by the EPA. An example of this hierarchy published by Stanford Dining in the context of food waste reduction is pictured in Figure 2.

Figure 2: R&DE Stanford Dining Food Waste Prevention Hierarchy

Finally, emissions from source reduction or internal reuse would normally be accounted for as part of an organization's purchased goods & services footprint, since they result in the university purchasing fewer goods. However, the Scope 3 Emissions Program has not yet formalized its approach to quantifying purchased goods & services on an annual basis; until that is done, there is not a systematic way to track the emissions benefits of reduced purchases. Even when Stanford's purchased goods & services emissions approach becomes formalized, the sheer volume of items included in the purchased goods & services category makes it difficult to identify the impact of small purchasing changes. When a methodology for purchased goods and services does become formalized, we will ensure that emissions reductions are not double counted between categories.

The resulting boundary for data included in this category is outlined below in Table 1, with deviations from guidance provided by the GHG Protocol—and conventional waste accounting—specifically indicated.

Table 1: Stanford Waste Data Boundary by Category Component

Category Component	Adheres to GHG Protocol Guidance	Conventionally Included in Waste Boundary	Included in Stanford's Waste Boundary
Solid Waste Treatment			
Waste reduced			✓
Waste reused			✓
Waste recycled		✓	✓
Waste composted		✓	✓

Waste disposed of in a landfill with methane recovery for electricity generation[2]		✓	✓
Solid Waste Transportation			
Transportation of all streams from Stanford to waste treatment facilities[3]	✓		✓
Shipping of recycled goods overseas	✓		✓
Wastewater Treatment[4]			
Wastewater treated aerobically	✓	✓	✓
Wastewater treated anaerobically	✓	✓	✓

Calculation Methodology & Results

Published and updated regularly by the EPA, WARM is the preeminent tool for calculating emissions from solid waste treatment and transportation in the United States. It encompasses the full life cycle impact of disposal across dozens of material types and disposal methods, including avoided emissions associated with different waste management practices and allows for the comparison of different treatment method scenarios. For instance, Stanford's internal methodology uses 38 combinations of material types and waste streams from WARM to calculate emissions directly, or to derive custom emission factors to best represent types of Stanford waste. Many more combinations are available that can be used directly or through custom emissions factors.

WARM was originally informed by the EPA Inventory of Greenhouse Gas Emissions and Sinks[5] and includes the most up to date data on national average emissions across the entire life cycle of each material type. Estimates related to transportation are built into the tool assuming an on-road transport distance of 20 miles for all streams. Finally, it also provides 9 customizations, as shown in Appendix A. The most impactful customization is the ability to indicate use of a landfill that uses methane recovery for electricity generation; it even allows entities to indicate the efficiency of landfill gas collection.

WARM is used by all three calculation tools experimented with by Scope 3 Emissions Program staff (VitalMetrics, SIMAP, and an internally developed model). However, the emissions results between tools vary significantly, as indicated in Table 2, highlighting that the key methodology differences between tools lie in the boundary components included, rather than in the sources of emissions factors.

Table 2: Total Waste Emissions by Source and Tool

Source	SIMAP	VitalMetrics	Internal
Solid Waste Treatment	-1,341	-27,766	-13,060
Solid Waste Transportation			2,224
Wastewater Treatment	184	N/A	184
Total Waste Emissions (MTCO2e)	**-1,157**	**-27,766**	**-10,653**

[2] Stanford only uses landfills that employ methane recovery, so this paper will be limited to discussion of landfills that perform methane recovery. Landfills that do not use methane recovery should also be included in an organization's footprint if applicable.

[3] Stanford does not currently include emissions from the transportation of reused goods because that data has not been tracked. Future improvements may include these emissions if that data becomes available.

[4] Wastewater transport is not conventionally considered an emissive activity in and of itself due to the use of existing sewer systems.

[5] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006." https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2006

The internal approach is the most comprehensive and customizable, with the following specific advantages:

- It includes emissions avoided from recycling and composting. While VitalMetrics also includes this using the WARM tool, SIMAP does not.
- It includes emissions avoided from reuse and source reduction, while the other tools do not.
- It allows precise accounting for transportation emissions based on the type of trucks used by Stanford's waste hauler, the distance traveled, and the fuel type. It also includes estimated emissions from shipping Stanford's recyclables overseas, including on-road transportation after arrival in the destination countries.
- It includes emissions from wastewater. While SIMAP also includes this, VitalMetrics does not.
- It utilizes the most precise emissions factors possible based on internal knowledge of the composition of each of Stanford's waste streams. This allows for a level of specificity not built into either the SIMAP or VitalMetrics calculations.

Table 2 also illustrates in the bottom row the wide range in total emissions produced by the various tools. For SIMAP, the emissions are relatively small because the boundary is small; SIMAP only includes emissions from landfilled waste, a small portion of compost that is used directly by Stanford as a soil amendment, and wastewater. On the other hand, the VitalMetrics emissions are large (in absolute value) because they apply average factors for all waste streams, rather than mapping to more precise types of material that characterize each stream. For example, for Stanford's recycling stream, the internal methodology applies 14 different emissions factors, such as HDPE, Carpet, and Corrugated Containers, while VitalMetrics applies a single averaged emissions factor for Mixed Recyclables. Additionally, VitalMetrics uses factors that are not specific to all Stanford's waste transit methods (on-road and waterborne shipping) or distances. Overall, the custom approach provides more specificity and precision to arrive at a more comprehensive assessment of Stanford's emissions from waste.

Based on these results, Scope 3 Emissions Program staff recommend the internal methodology for calculating waste emissions, with an emissions total for calendar year 2019 of -10,653 MTCO2e. Appendix A lays out not only the specific inputs, outputs, and calculation methodology used for internal calculations, but also by VitalMetrics and SIMAP as applicable, for documentation and comparison.

Discussion

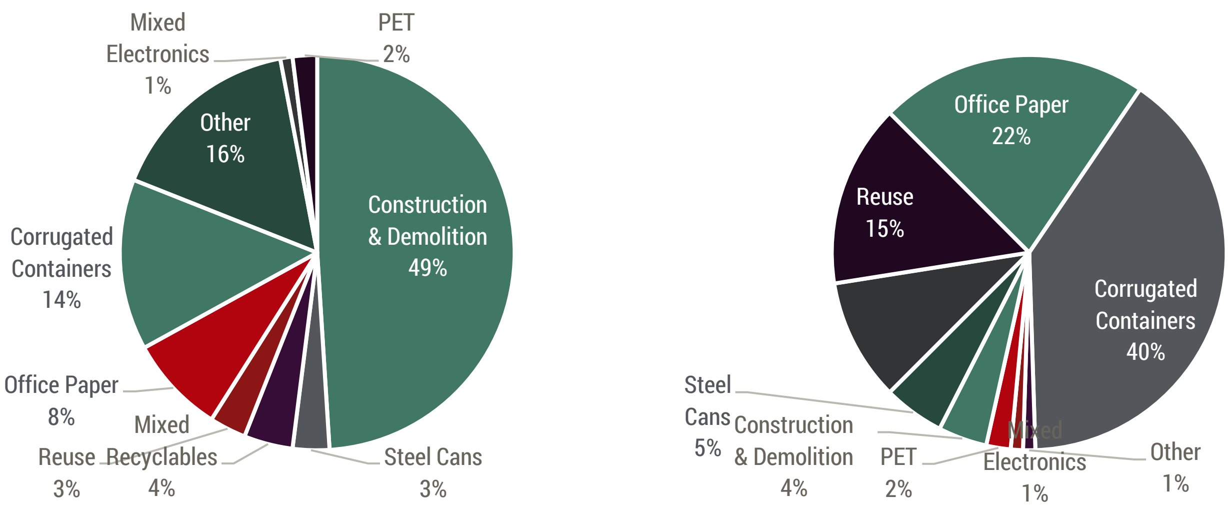
Results Analysis

Following the announcement of Stanford's goal to be Zero Waste by 2030, a Zero Waste Feasibility Study began in 2017, which provided in-depth characterization of Stanford's waste streams and laid the groundwork for Stanford's existing Zero Waste Plan. Many of the findings from that in-depth waste characterization are utilized for the emissions calculations discussed in this paper. Additionally, this waste characterization study showed that 26% of the material currently landfilled could be recycled and 36% could be composted. Diverting this material into the right stream could lead to a diversion rate as high as 94%.

Recovering these items from the landfill also affects emissions in two ways: it avoids any positive emissions associated with landfilling the items and adds avoided emissions from recycling or composting the item and thereby preventing the extraction of additional raw materials and/or increasing soil carbon capture. When considering landfill, it is first important to note the meaningful impact of utilizing a landfill that employs methane recovery for electricity generation. If Stanford did not utilize a landfill with this technology, our waste footprint could be thousands of metric tons higher than it is today. Because we do use a landfill with this technology, landfill emissions are actually negative for most material types, but recycling and composting emissions are more negative. **Therefore, there is still a benefit to recycling and composting applicable materials instead of landfilling them.**

Figure 1 in the Executive Summary shows that recycling activities have the most positive impact on Stanford's waste-related emissions. To expand on this, Figure 3 below shows a side-by-side comparison of tonnage and avoided emissions from recycling, reuse, and source reduction by material type in CY19.

Figure 3: CY19 Tonnage (left) & Avoided Emissions (right) from Recycling by Material Type



There are several key takeaways from Figure 3:

- Corrugated containers (in other words, cardboard boxes) and office paper are high in tonnage and in emissions avoided. In fact, these categories have the second and third most negative emissions intensity of all recycled materials, respectively (behind aluminum cans). Thus, ensuring that cardboard boxes and office paper are recycled presents one of our largest emissions avoidance opportunities. As Stanford and its vendors implement programs to reduce the number of cardboard boxes used as packaging and office paper used in printing and other applications, emissions avoidance will be even greater: **the emissions factors for *source reducing* these items are 2 to 3 times that of *recycling* them.**
- There is a high tonnage of construction & demolition waste at Stanford, but this material results in relatively low avoided emissions. There are two reasons for this:
  - Metal is the most recyclable component of construction & demolition waste. Other waste in this category is less recyclable and is sometimes used as alternative daily cover, or cover material placed on top of landfilled items each day to control fires, odors, blowing litter, etc. It is permitted to consider material used for alternative daily cover as recycling because it replaces the use of earthen material, but this practice is associated with a much lower emissions factor than true recycling.
  - Stanford does not currently collect the weight of construction & demolition waste by material type, so we have used a median emissions factor instead of factors for precise materials. This represents a potential improvement to our methodology in future years.
- Reuse & source reduction programs have high emissions impact relative to tonnage, suggesting that existing programs like the Reuse website, the Furniture Reutilization Program, Give & Go (R&DE's annual student move out

campaign) and R&DE Stanford Dining's Food Waste Prevention program should continue to be supported and expanded as needed.

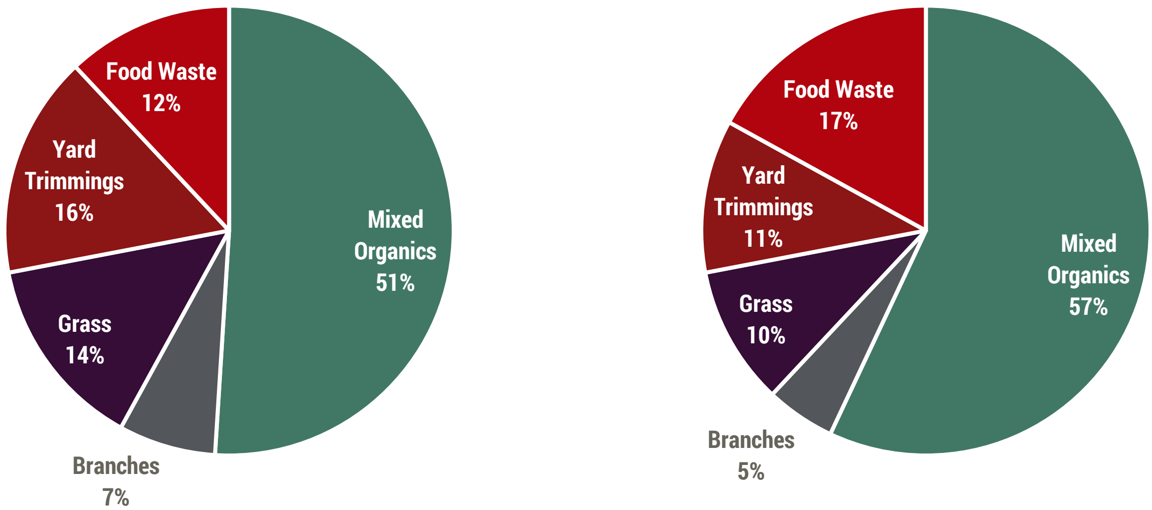
In discussing recycling, the issue of transparency as to what happens to our recycled goods after they leave campus is important to note. The university receives reports from our recycling facilities showing where the recycled goods are shipped overseas (this informs the university's customized transportation calculations) and what they are used to create, but this doesn't' fully eliminate the risk of recyclables ending up in the landfill or incinerator. Similarly, some recycling is hauled off campus by contractors; when this happens, the material types, tonnages, and final destinations of these goods are not consistently reported, presenting another gap in our knowledge of recycled goods. These gaps are currently recognized but not accounted for in any way in the footprint presented in this paper.

Composting does not play as strong a role in avoiding emissions as recycling does; it currently only contributes 5% of the university's avoided emissions, even though roughly the same tonnage of material is composted as is recycled (about 8,000 tons are disposed of in each stream per year). Whereas the average recycling emissions factor for Stanford's materials is -2.29 MTCO2e/ton, the average compost emissions factor is -.08 MTCO2e/ton.

The primary environmental benefit of compost is that it increases carbon capture in the soil to which it is applied. However, the overall positive effect of this increased carbon capture is not as strong as the overall effect of avoiding the extraction of new materials from recycling existing goods. On the other hand, there may be benefits from composting that are not fully reflected in the compost emissions factor available from WARM, and compost plays a significant role in the university's diversion goals. Figure 4 below shows a side-by-side comparison of tonnage and avoided emissions from composting by material type in CY19.

Mixed Organics includes compost from all building-level compost bins; it can include food waste, compostable plastics, food-soiled paper, and other organic material. Figure 4 suggests that while Mixed Organics are the largest source of our compost and the largest contributor to our current avoided emissions, food waste has the highest impact in terms of CO2e avoided per ton. However, as the food waste hierarchy in Figure 2 depicts, source reducing and donating our food—or even turning it into animal feed as is current practice—are all higher impact uses for food waste than composting it and should therefore continue to be prioritized.

Figure 4: Tonnage (left) & Avoided Emissions (right) from Composting Material Type



**Food waste from Stanford dining halls is converted to animal feed but has been included in these visualizations since it is organic material.*

Stanford's existing Zero Waste Plan has identified 50 strategies to further reduce overall waste generation and increase diversion. The pathway to zero waste lists grouped strategies that will steadily improve our diversion rates and reduce landfill waste over time; it is also shown in Figure 5.

Figure 5: Stanford Pathway to Zero Waste

Grouped Reduction Options	Cumulative Percent Diverted	Year
Current Programs	64%	2020
Enhanced reuse programs	65%	2022
Improved recycling & composting in Stanford cafes	71%	2023
Convert to single stream recycling	73%	2025
Expanded recycling infrastructure & programs	76%	2026
Athletics event recycling & composting	77%	2027
Food rescue and donation programs	78%	2028
Procurement programs	82%	2029
Expanded composting programs	86%	2030
Expand common area waste stations in offices	90%	2030
Lab recycling & composting programs	91%	2030
Expanded R&DE infrastructure & programs	93%	2030

Of the grouped programs listed here, enhanced reuse programs, converting to single stream recycling, expanded recycling infrastructure & programs, food rescue and donation programs, and procurement programs will have the largest effects on the university's waste emissions. Specific high impact strategies identified in the Zero Waste Plan are:

- Centralized collection of waste to increase diversion
- Increase uptake of the reuse website
- Expand the Furniture Reutilization Program
- Expanded food recovery from cafes and catered events
- Carpet recycling during building renovations
- Procurement and vendor partnerships to decrease packaging and increase recyclability of purchased goods
- Expanded reduction programs like Cardinal Print and Cardinal Clean
- Transition to single stream recycling on the main campus, where all recyclables are disposed of in the same bin (this is already the system at the Redwood City campus)
- Improved tracking of construction & demolition waste

The Scope 3 Emissions Program recommends prioritizing these opportunities so as to achieve positive emissions impacts as early as possible.

Waste *reduction* programs pose a particularly impactful opportunity to achieve both emissions avoidance and the university's diversion goals. One opportunity in this space is to improve tracking for existing reduction programs, including Cardinal Print, R&DE Stanford Dining's Food Choice Architecture program, and R&DE's Cardinal Clean program. The Scope 3 Emissions Program has recently established a tracking system for waste reduced through these programs and will develop a specific methodology for including these avoided emissions in Stanford's waste footprint in partnership with the waste working team that is comprised of the collaborators and approvers listed in the Executive Summary. For example, this working team will consider how to ensure that the reductions we include would not have otherwise occurred and will determine the time-frame over which we should include those reductions in our footprint. This team will also consider opportunities to expand reduction programs.

Finally, as shown in Figure 1 in the Executive Summary, while solid waste treatment decisions have the most significant impact on Stanford's waste emissions, waste transportation has the highest positive emissions. A recent analysis of waste transportation methods illustrated that there is a potential to reduce transportation-related emissions by up to 1,800 MTCO2e with the use of shorter routes, fewer trips, and electric trucks. The University may consider these strategies over the long term as well.

Future Considerations

Of the three elements that comprise the waste footprint—solid waste treatment, solid waste transportation, and wastewater treatment—wastewater has by far the least significant impact. Thus, Scope 3 Emissions Program staff propose collecting wastewater data and calculating wastewater emissions on a less frequent basis than for solid waste emissions.

There are also broader philosophical ideas that should be considered as Stanford advances its emissions quantification efforts in the waste category.

- If the university were to engage in ESG reporting, would we adapt our methodology or publish an "internal" and "external" number?

- There are well-known concerns in the recycling industry regarding whether materials are actually recycled when they reach their destinations, especially if that destination is overseas. In other words, the life cycle stages of materials at the end of their lives can be just as complex and non-transparent as the life cycle stages associated with supply chain at the beginning of life. Should Stanford take this into account? One option would be to exclude material types for which there is little traceability. Luckily, Stanford's most impactful recyclables (corrugated cardboard and office paper) currently have high traceability. Streams with the least traceability are plastics, which comprise only a small portion of Stanford's currently calculated waste emissions.
- As the university moves towards single stream recycling as part of the Zero Waste Plan, the traceability and recyclability of cardboard and paper will decrease. However, single stream recycling will also increase the total amount of material that gets recycled due to convenience and decreased sorting confusion.
    - Traceability will decrease because the university likely will not receive as thorough and granular reporting from the single stream recycling facilities as we are able to get now. It is estimated that this less granular reporting may impact our emissions calculations by about 5%.
    - Recyclability will decrease because paper and cardboard are often contaminated with liquid and food when they are recycled in the same bin as plastics and glass, which makes them un-recyclable. Given an estimation that as much as 25% of paper goods entering single stream recycling are contaminated, this contamination may increase the university's waste emissions by up to 10%.[6]
- Many items disposed of in Stanford's waste stream are purchased by students or related to packaging and therefore are not directly included in Stanford's purchased goods & services emissions. In our current accounting methodology, we are taking credit for the positive effects of disposing of those materials in a responsible way, but we are not including the "penalty" related to extraction, manufacturing, and transportation of that good to our campus. Should this be considered as the process for accounting for purchased goods & services is formalized?
- Consider increasing the parity between reporting on scope 3 emissions from purchased goods & services and waste. Contextualize waste results with purchased goods & services results in reporting to highlight trade-offs.
- Collect data from other facilities in Stanford's operational control, such as Hopkins Marine Station, SAL-III library in Livermore, other leased offices, rented student apartments managed by R&DE, and rentals managed through Faculty Staff Housing.
- Stay apprised of changes in the field. WARM emissions factors are updated regularly based on changes in the industry. The recycling industry is particularly volatile, especially in terms of the demand, destinations, and validity of recycling practices, so significant changes can come about quickly. On the positive side, demand for materials with more recycled content has increased over time, which should continue to make the emissions factors associated with recycling more negative.
- Stay apprised of changes at Stanford. As the university transitions to a single stream recycling system (instead of separating plastics/metals/glass from paper), there could be changes to the recyclability of these materials.

Conclusion

Using the internal model, we estimate scope 3 emissions from waste to be -10,653 MTCO2e in CY2019. The negative number illustrates that Stanford's robust source reduction, reuse, recycling, and composting programs have a less detrimental effect on the environment than they could. This effect will continue as the university progresses towards its goal of zero waste by

[6] FiveThirtyEight, "The Era of Easy Recycling May Be Coming to An End." ABC News. 2019. https://fivethirtyeight.com/features/the-era-of-easy-recycling-may-be-coming-to-an-end/

2030. A renewed focus on diverting recyclables out of the landfill and developing and tracking waste reuse and reduction programs in the coming years will allow the university to achieve greater impact most quickly and effectively. The Office of Sustainability, R&DE, Business Affairs, and waste haulers have collaborated for decades to build out the reduction, reuse, recycling, and composting programs that exist today and educate the campus community about proper waste disposal. Continued collaboration and alignment of waste efforts across the university will be essential as the university charts a path towards both zero waste and decreased emissions from waste.

Appendix A: Detailed Calculation Methodology

Initial quantification of emissions in this category was completed by the Office of Sustainability prior to creation of the Scope 3 Emission Program. Program staff have collaborated with the Office of Sustainability to include summaries of that work in this paper along with more recent calculations.

Almost all emissions data available for waste disposal in the United States comes from the U.S. Environmental Protection Agency (EPA). The following tools are commonly referenced:

- **WARM:** Model published by the EPA that communicates life cycle impacts, including avoided emissions associated with different waste management practices. This tool allows for the comparison of different treatment method scenarios and is ideal for decision-makers. This is by far the preeminent tool in the United States for calculating greenhouse gas emissions associated with solid waste treatment and transportation.
- **EPA Inventory of Greenhouse Gas Emissions & Sinks, 1990-2006[7]:** Developed by the U.S. government to meet its commitment under the UN Framework Convention on Climate Change, this paper identifies and quantifies anthropogenic sources of emissions in the United States, including from energy harvesting and combustion, industrial processes, agriculture, land use, and waste. This paper synthesizes findings from US-wide studies on wastewater treatment, energy generation, transportation, and other activities.[8]
- **EPA U.S. Emissions Factor Hub:** database published by the EPA every 2-3 years with easy-to-use emission factors for organizational greenhouse gas reporting. This source provides emission factors associated with major contributors to Scopes 1, 2, and 3 footprints, including stationary and mobile combustion, upstream and downstream transportation, waste generated in operations, and more.[9]

The sources described above are each referenced by calculation tools in unique ways, although all calculation tools primarily reference WARM for solid waste. The calculation tools included in this analysis are:

- **The Sustainability Indicator Management & Analysis Platform (SIMAP):** Created by the University of New Hampshire, the SIMAP tool helps universities quantify emissions in scope 1, 2, and some scope 3 categories that are particularly applicable to higher education, including commuting, business travel & study abroad, student travel to/from home, food, paper, fuel and energy activities, and waste & wastewater. The tool is publicly available for a minor membership fee of $600 per year.

VitalMetrics Carbon360 Platform: Carbon360 is a proprietary, cloud-based solution developed at the University of Santa Barbara and now owned by VitalMetrics. The tool pulls emissions factors from a combination of databases, including its proprietary database called CEDA, to make it simple for customers to calculate scope 1, 2, and 3 emissions across the fifteen categories defined by the GHG Protocol. This tool cost Stanford $10,000 in its first year to deploy.

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[7] EPA, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006." https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2006

[8] According to EPA records of WARM model updates, iterations of its "Inventory of Greenhouse Gas Emissions & Sinks" are incorporated into the underlying data for WARM, namely on the carbon content of fuels, landfill methane generation distribution (by type of landfill), and landfill gas recovery and flaring rates. The most recent iteration of the EPA Inventory of Greenhouse Gas Emissions & Sinks is from 2016.

[9] While the EPA Emissions Factor hub includes waste related emission factors, this emission factor set accounts only for emissions released from the site of disposal through the treatment of waste but does not include avoided emissions from the extraction of new raw materials and therefore does not meet Stanford's boundary requirements. This emissions factor set was therefore only used for transportation-related emissions factors.

- **Intenal methodology:** Because EPA emissions factors are publicly available, Scope 3 Emissions Program staff utilized these emissions factors to develop a third estimate of emissions for waste to compare to the outputs of the other two tools. Specifically, the WARM model was used for solid waste treatment estimates, the EPA Inventory of Greenhouse Gas Emissions & Sinks was used for wastewater treatment estimates, and customized calculations using vehicle emissions factors from the U.S. Emissions Factor Hub were used for transportation emissions. Two waste types used non-WARM emissions factors due to poor material fit with WARM material categories. Information on these customizations is found below in the "Reuse & Reduction" notes on the internal methodology.

Table A-1 illustrates which emissions factors each tool applies for each component of Stanford's selected boundary. This exercise highlights that the key methodology differences between tools lie in what boundary components are included, rather than the sources of emissions factors.

Table A-1: Emissions Factor Sources referenced by Calculation Tool

Category Component	SIMAP	VitalMetrics	Internal
Solid Waste Treatment			
Waste reduced	N/A	N/A	WARM
Waste reused	N/A	N/A	WARM, DEFRA, FIRA
Waste recycled	N/A	WARM	WARM
Waste composted	WARM	WARM	WARM
Waste disposed of in landfills that employ methane recovery exclusively	WARM	N/A	WARM
Waste disposed of in landfills that employ the national average rate of methane recovery	N/A	WARM	N/A
Solid Waste Transportation			
Transportation of all streams from Stanford to waste treatment facilities	WARM	WARM	EPA Emissions Factor Hub (vehicle emissions factors)
Shipping of recycled goods overseas	N/A	N/A	EPA Emissions Factor Hub (vehicle & fuel emissions factors)
Wastewater Treatment			
Wastewater treated aerobically	EPA Inventory of Greenhouse Gas Emissions & Sinks	N/A	EPA Inventory of Greenhouse Gas Emissions & Sinks
Wastewater treated anaerobically	EPA Inventory of Greenhouse Gas Emissions & Sinks	N/A	EPA Inventory of Greenhouse Gas Emissions & Sinks

All activity data used in this category comes from information collected by the Office of Sustainability. Waste tonnages are collected by the Zero Waste team from Stanford's waste haulers on a regular interval: some haulers provide annual reports, and some report data monthly and the Zero Waste team aggregates this data into annual reports. Waste characterization data from studies organized by the Office of Sustainability have also informed some material type data in our emissions analysis. The Tool Inputs sections further describes the processes for generating input data. This input data is typically used across all tools, as boundary requirements permit.

Solid Waste Treatment

Tool Inputs

For solid waste from the main campus, the material type and waste stream in which it was disposed inform the emissions footprint. The Zero Waste team collects monthly data in 66 material categories and aggregates it on an annual basis. Appendix B contains the table of all raw material categories and associated weights for CY19. For solid waste from Stanford's Redwood City campus, the Zero Waste team collects annual data that show gross volume picked up by the waste hauler for each waste stream. Emissions from the solid waste from Stanford's Redwood City account for only 0.2% of all emissions from solid waste, rendering its emissions almost negligible relative to those from main campus solid waste treatment. Appendix B provides the annual tonnage, overall emission factors, and associated emissions for each waste stream from the Redwood City campus. A roll-up of the raw data from both campuses is presented in Table A-2, as well as a description of the material types that comprise each waste stream. Landfill waste was disaggregated using the findings of a waste characterization study that was performed in 2019 in conjunction with the zero waste planning process.

These tonnage inputs were used for each of the three calculation approaches described in the sections that follow.

Table A-2: CY19 Weight by Waste Stream

Waste Stream	Stanford Waste Included	Short Tons
Compost	Yard Trimmings, Animal Bedding, Food Scraps, Stable Waste,Grasscycling, Animal Feed, Brush, Wood Waste, Wood Mixed, Logs to Chips, Brush to Chips	**7,075**
Landfill	Plastics, Aluminum Cans, Carpet, Corrugated Containers, Electronic Peripherals, Food Waste, Furniture, Glass, Mixed Metals, Mixed MSW, Mixed Organics, Mixed Paper, Construction & Demolition Waste	**8,981**
Recycle	Aluminum Cans, Carpet, Concrete, Old Corrugated Containers, Computer Monitors	**9,116**
Reuse	Mattresses, Clothing/Textiles, Furniture, Food Donations	**1,248**

Internal Methodology

WARM emissions factors from 2019 were used to calculate the emissions associated with nearly all waste, except for those from reused mattresses and clothing, which were assigned a source reduction emission factor derived from other sources.[10] Scope 3 Emissions Program staff mapped the raw data collected in Table B-1 to the appropriate waste stream/material category grouping in WARM. If a raw data material type in Table B-1 was likely comprised of mixed materials with components that had WARM emission factors available, a custom emission factor was made. Staff made data-based assumptions about composition of the waste, gathering their associated EPA WARM Emission Factors, and calculating an overall emissions factor based on this assumed mix. The waste stream, material type, CY19 tonnage, emission factors, emissions results, and emission factor sources for the internal solid waste footprint are provided in Table A-3.

Table A-3: Emissions Results by Waste Stream and Material Type

[10] EPA Waste Reduction Model, Version 15. https://www.epa.gov/warm/versions-waste-reduction-model-warm#15

Waste Stream	EF Material	Sum of Short Tons of Waste	Average of EF	Sum of Emissions
Compost	Branches	560.39	-0.06	-31.90
Compost	Grass	1119.96	-0.06	-63.66
Compost	Mixed Organics	4136.03	-0.09	-371.07
Compost	Yard Trimmings	1254.15	-0.06	-71.19
Landfill	#1& #2: PET & HDPE	231.84	0.02	3.93
Landfill	2019 Furniture	171.60	0.02	2.91
Landfill	Aluminum Cans	38.84	0.02	0.66
Landfill	Carpet	2.72	0.02	0.05
Landfill	Corrugated Containers	435.50	-0.37	-162.17
Landfill	Custom	522.53	-0.34	-178.24
Landfill	Electronic Peripherals	48.14	0.02	0.82
Landfill	Food Waste	2394.34	0.25	604.72
Landfill	Glass	277.65	0.02	4.71
Landfill	HDPE	46.02	0.02	0.78
Landfill	LDPE	723.29	0.02	12.27
Landfill	Mixed #3-#7: PVC, LDPE, PP, PS, Other	252.49	0.02	4.28
Landfill	Mixed Metals	293.70	0.02	4.98
Landfill	Mixed MSW	473.49	0.00	-1.77
Landfill	Mixed Organics	97.43	-0.01	-1.06
Landfill	Mixed Paper (general)	1849.09	-0.41	-752.70
Landfill	Mixed Paper (primarily from offices)	354.81	-0.30	-108.07
Landfill	Mixed Plastics	160.72	0.02	2.73
Landfill	PET	114.87	0.02	1.95
Landfill	PLA	63.67	-1.65	-104.78
Landfill	PP	11.78	0.02	0.20
Landfill	PS	75.43	0.02	1.28
Landfill	Single Use Coffee Cups	127.33	-0.39	-50.21
Landfill	SU: Custom Construction Mix	91.63	0.02	1.55
Landfill	Yard Trimmings	111.11	-0.33	-36.45
Recycle	Aluminum Cans	4.96	-9.13	-45.29
Recycle	Carpet	0.97	-2.38	-2.31
Recycle	Concrete	874.38	-0.01	-9.78
Recycle	Corrugated Containers	1366.17	-3.14	-4287.89
Recycle	Flat-Panel Display	1.69	-0.99	-1.68
Recycle	Glass	130.18	-0.28	-36.37
Recycle	HDPE	14.57	-0.76	-11.09
Recycle	Mixed Electronics	138.32	-0.79	-109.08
Recycle	Mixed Plastics	0.35	-2.66	-0.93
Recycle	Mixed Recyclables	381.46	-2.86	-1089.67

Recycle	Office Paper	800.51	-2.87	-2293.49
Recycle	PET	171.77	-1.04	-178.47
Recycle	Steel Cans	284.37	-1.84	-521.92
Recycle	SU Custom Construction Mix	4921.93	-0.08	-414.15
Reuse	Clothing/textiles reuse/recycling	65.91	-22.31	-1470.45
Reuse	Food Waste	89.30	-3.55	-317.00
Reuse	Furniture (custom) 2019	113.34	-3.65	-413.69
Reuse	Grains	952.43	-0.62	-591.67
Reuse	Mattress (new)	26.74	1.71	45.77

This table above rolls up waste information at the level of assigned emissions factors. Please see table B-1 In the Appendix for an itemized breakdown of all Stanford materials that were mapped to these emission factors above.

Construction & Demolition Waste Recycling

Stanford created a custom emissions factor for construction and demolition waste that is recycled. Since only gross weight of construction and demolition waste recycled is available from Stanford's landfill (without compositional details), the Scope 3 program team assumed the emission factor to be the median emission factor between Asphalt Concrete, Concrete, Dimensional Lumber, Drywall, and Structural Steel.

Reuse & Reduction

To estimate emissions from reusing materials, the EPA advises to find the GHG footprint of all reduced or reused materials using its "source reduction" emissions factors in WARM. In WARM, source reduction is "measured by the amount of material that would otherwise be produced but is not generated due to a program promoting waste minimization or source reduction."[11] The avoided GHG emissions in WARM are based on raw material acquisition and manufacturing processes for the current industry-average mix of virgin and recycled inputs for the marketplace.

Finally, the EPA also provides specific guidance on accounting for food donations,[12] which suggests the application of a loss factor to the weight of donated food to account for spoilage. Based on this guidance, the default loss factor of 3% was applied to the weight of Stanford's food donations in CY19 before applying the corresponding emissions factor(s).

EPA WARM source reduction emission factors were used for almost all materials. Two exceptions were made for materials that had low compatibility with the EPA WARM material types. Specifically, source reduction emission factors for mattresses and clothing reuse were derived using publicly available emission factors for production of these goods to the point of sale.

[11] EPA Documentation for Greenhouse Gas Energy Factors Used in the Waste Reduction Model. Page 22, Section 1.4.2.2. https://www.epa.gov/sites/default/files/2020-12/documents/warm_background_v15_10-29-2020.pdf
[12] EPA, "Modeling Food Donation Benefits in EPA's Waste Reduction Mode." https://www.epa.gov/sites/default/files/2019-06/documents/warm_v15_food_donation_guidance.pdf

For clothing reuse, a DEFRA emission factor for clothing production was used,[13] and for mattress use, a Furniture Research Association report was used that quantified emissions from producing a mix of single and queen mattresses.[14]

Food Waste Converted to Animal Feed

Stanford's food waste from dining halls is transported off-site to livestock farms for use as animal feed. For emissions modeling purposes, this disposal method has the assumed impact of preventing production of regular livestock feed, which is typically made from grains. The "Source Reduction" emission factor for grains was applied to Stanford's weight of animal feed to reflect the carbon savings of preventing grain production of the same volume. The resulting emissions were estimated at -591.67 MT CO2e. However, the emissions savings from feeding animals food waste may be overstated, since it is unlikely that the food waste will prevent the exact same volume of grain production for livestock feed.

Other Customizations

WARM offers customizations within the tool itself to make waste emissions accounting even more precise. The customizations available in WARM are shown in Table A-4, with Stanford's selections provided for reference where applicable.

<u>Table A-4:</u> WARM Customizations & Stanford Selections

Customization Feature	Stanford's Selection
For avoided electricity-related emissions in the landfilling and combustion pathways, indicate the state for which you are conducting the analysis	National Average
For recycling, calculate emissions savings under the assumption that the material would have been manufactured from 100% virgin inputs, or from the current mix of virgin and recycled material	Current Mix
For landfill treatment, indicate whether to use the National Average prevalence of landfill-gas-recovery (LFG), no landfill gas recovery, or all landfill gas recovery	LFG Recovery
If your landfill has gas recovery, indicate if it recovers methane for energy or flare it	Recover for energy
Indicate landfill gas collection efficiency	California regulatory collection
Which of the following moisture conditions and associated MSW decay rate most accurately describes the average conditions at the landfill?	National average
For anaerobic digestion, indicate whether wet or dry digestion is being performed.	N/A
For anaerobic digestion, select whether the digestate resulting from your anaerobic digester is cured before land application.	N/A
Indicate transport distances for the various MSW management options.	N/A – See Internal Methodology Solid Waste Transportation section below

For landfilled waste, the Scope 3 Emissions program used WARM's customization features to indicate that our landfilled waste goes to landfill facilities that perform landfill gas recovery and energy generation. Stanford's landfill facility for municipal solid

[13] DEFRA, GHG Conversion Factors 2022 for advanced users, 'Material Use' tab. Please note that while the tab is labeled "Material Use," documentation at the top of the page indicates that emission factors only reflect emissions up to the point of sale of a good, and excludes emissions from the use phase of goods, or end of life.
[14] FIRA, "Benchmarking Carbon Footprints of Furniture Products." http://www.healthyworkstations.com/resources/Environment/FIRA.CarbonFootprint.pdf

waste—the Newby Island Landfill—recovers methane produced by its waste, which it burns to generate electricity.[15] However, not all landfills that perform methane recovery achieve the same levels of methane capture efficiency. In California, landfills that perform gas recovery are subject to regulatory requirements to achieve aggressive methane recovery rates. For instance, a typical landfill performing methane recovery achieves 50% recovery in 2-4 years, whereas California requires landfills to achieve 50% recovery in 1 year, according to the WARM model.[16] This advanced level of methane recovery is accounted for in the internal emission footprint through the response "California regulatory collection" reflected in Table A-4.

Based on the sum of the Annual Emissions column in Table 5, total CY19 emissions from solid waste treatment using the internal methodology are -13,060 MTCO2e.

SIMAP

SIMAP only estimates solid waste treatment emissions associated with landfilled waste and compost used as a soil amendment. Table A-5 illustrates how the university's raw data was rolled up into these categories, the corresponding emissions factors used by SIMAP, and the results.

Table A-5: SIMAP Emissions by Waste Stream & Material Type

Waste Stream	Material	Weight (short tons)	Emissions Factor (MTCO2e/ton)	Total Emissions (MTCO2e)	Mapping Notes
Landfill	Mixed	8,981	-0.03	-269	Based on waste characterization study, this landfill waste is presumed to be part aluminum, ferrous metals, glass, organic waste, paper, plastic, and mixed other wastes
Compost	Compost used as Soil Amendment	3,645	-.29	-1,072	Includes stable waste, grasscycling, brush to chips, and logs to chips

SIMAP emission factors for solid waste are taken from WARM. SIMAP calculated landfill emissions by taking the total weight of all landfilled materials and applying the WARM emissions factor specific to landfills with methane recovery and electricity generation. Given that SIMAP's method does not incorporate material-specific landfill emission factors, its methodology is considered less precise than the internal approach.

In addition to landfill waste, SIMAP calculated emissions savings associated with compost used directly on campus as a soil amendment. The chemical process of composting sequesters carbon into the soil, so it results in a net loss of carbon in the atmosphere. According to SIMAP, only compost used as a soil amendment on campus should qualify as a sink, whereas the WARM model considers all material composted to be a sink, no matter where the finished product is applied.

[15] The Center for Land Use Interpretation, "Newby Island Landfill, California." https://clui.org/ludb/site/newby-island-landfill

[16] EPA Waste Reduction Model, Version 15. https://www.epa.gov/warm/versions-waste-reduction-model-warm#15, 'Analysis Inputs' tab, Question 7. Based on an EPA literature review of field measurements and expert discussion, a range of collection efficiencies was estimated for a series of different landfill scenarios.

SIMAP does not calculate emissions from recycled waste, or from organic waste that is composted but not used directly as a soil amendment. According to SIMAP, recycling is not taken into account separately because recycling diversion is indirectly taken into account when considering the volume of landfill refuse produced. This rationale accounts for the diminished landfill emissions of recycling, but not for the avoided extraction of raw materials.

Finally, SIMAP does not provide enough information on its methodology for solid waste transportation to disaggregate transport emissions from treatment emissions. Therefore, the totals reflected above also include transportation of waste in each stream.

Based on the sum of the Total Emissions column in Table 7, total CY19 emissions from solid waste treatment using SIMAP are -1,341 MTCO2e. Note that because SIMAP excludes emissions from recycling, most composting, reuse and reduction, this total does not align with Stanford's defined waste boundary and therefore is not considered to be comprehensive.

VitalMetrics

The VitalMetrics Carbon360 tool also uses WARM to calculate emissions from waste, but does not assign categories as granularly as the internal methodology. VitalMetrics categorized Stanford's waste as either Aluminum, Ferrous Metals, Glass, Organic Waste, Paper, Plastics, and Others (mixed waste). VitalMetrics does not provide disaggregated transport emissions in its reporting, so the figures below include aggregated treatment and transport emissions.

Table A-6 illustrates how the university's raw data was rolled up into the overarching material categories used by VitalMetrics, the corresponding emissions factors used by VitalMetrics (from WARM), and the results in MTCO2e.

<u>Table A-6:</u> VitalMetrics Emissions by Waste Stream & Material Type

Waste Stream	Material	Weight (short tons)	Total Emissions (MTCO2e)	Mapping Notes
Compost	Organic Waste	8,025	-609	Yard Trimmings, Animal Bedding, Food Scraps, Stable Waste, Grasscycling, Animal Feed, Brush, Wood Waste, Logs To Chips, Brush To Chips, Wood Mixed
Recyclables	Aluminum	5	-45	Aluminum Foil, Aluminum Scrap, Copper/Brass, Aluminum Cans
Recyclables	Ferrous Metals	284	-520	Tin, Tin Cans, Scrap Metal
Recyclables	Glass	130	-36	Mixed Glass
Recyclables	Paper	2,166	-7,675	Corrugated Containers, Confidential Paper, Supermix/Office Pack

Recyclables	Plastic	187	-172	CHDPE #2, NHDPE #2, Styrofoam, Plastic Caging, PET #1
Recyclables	Others (Mixed Waste	6,636	-18,849	Construction & Demolition Waste, E-waste, Unsorted Plastic, Metal, & Glass, Mixed Debris
Landfill	Aluminum	39	1	Estimated using waste characterization study
Landfill	Ferrous Metals	293	7	Estimated based on waste characterization study
Landfill	Glass	255	6	Estimated based on waste characterization study
Landfill	Organic Waste	2,627	220	Estimated based on waste characterization study
Landfill	Others (mixed waste)	1,916	266	Municipal Solid Waste (MSW) for which Stanford does not have more granular data
Landfill	Paper	2289	-397	Estimated based on waste characterization study
Landfill	Plastics	1,561	36	Estimated based on waste characterization study

Based on the sum of the Total Emissions column in Table 7, total CY19 emissions from solid waste treatment using VitalMetrics are -27,767. Note that because VitalMetrics uses less granular material type methodologies, it is considered to be less accurate than the internal methodology. Additionally, its results use WARM's output for the "national average" rate of methane recovery in landfills, rather than the assumption that all landfills Stanford uses perform methane recovery with electricity generation.

Solid Waste Transportation

Tool Inputs

Stanford's haulers shared data on all trips required to transport Stanford's goods in 2019. From this data, Office of Sustainability staff calculated the number of miles of on-road transport for all waste streams, as well as the number of ton-miles for waterborne shipment for overseas transport of recycled goods. The results of this analysis are shown in Table A-7 below.

Table A-7: Stanford CY19 Waste On-Road & Waterborne Miles Traveled

Waste Stream	On-road Miles Traveled by Waste Leaving Campus	Ton-Miles by Waterborne Shipping Vessel
Landfill	66,572	N/A
Recycling	107,927	35,200,562
Compost	55,834	N/A
Re-use	N/A	N/A

Internal Methodology

For on-road transport, Office of Sustainability staff determined total annual mileage per waste stream by multiplying the distance to each destination by the number of round trips driven in a year between campus and the waste treatment facilities. The program staff assumed on-road vehicles to be Medium- and Heavy-Duty Vehicles powered by diesel and used a fuel efficiency assumption of 3 miles per gallon. On-road vehicle miles for recycling also includes the assumed on-road distance that waste travels upon reaching the port in its destination country to its treatment facility. On-road transport for waste leaving Stanford's campuses are broken down in table A-7.

Stanford's waste haulers ship a portion of Stanford's recycled goods overseas. Specifically, goods are transported from the Port of Oakland to Indonesia, Malaysia, Vietnam, and Thailand. For overseas shipment of recycled goods, Scope 3 Program staff followed EPA guidance on calculating ton-miles of goods shipped to these destinations, such that EPA emission factors for Waterborne Crafts could be applied. Mileage traveled includes round-trips to and from destination countries. For waterborne transport of these recyclables, "Waterborne Craft" emission factors were used from the EPA, as shown in Table A-8.

Table A-8: EPA-Sourced Emissions Factors for On-Road and Overseas Transportation of Solid Waste

Vehicle Type	Fuel Type	Emission Factor	Unit
Medium- and Heavy-Duty Vehicles	Diesel	3.42[17]	Kg CO2e/vehicle-mile
Waterborne Craft	-	0.041	kg CO2e/ton-mile

To plug these custom transportation calculations into the WARM tool, it was necessary to subtract out the more generic transportation calculations currently used by WARM. To accomplish this, the Scope 3 Program team manually extricated transportation related emissions from WARM by using the WARM transportation distance customization feature to calculate the average emissions per additional mile traveled for each material and waste stream. Then, the additional emissions per mile

[17] EPA Emission Factor Hub 2020. CH4 and N2O emissions per mile taken from Table 4: Mobile Combustion CH4 and N2O for On-Road Diesel & CO2 emissions per gallon diesel taken from Table 2: Mobile Combustion CO2. A fuel economy of 3 miles per gallon was assumed for garbage trucks. https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_mar2020.pdf

traveled for each material were subtracted from the emissions estimates of a one mile traveled scenario and internally calculated transportation emissions were added as a replacement. The resulting emissions by waste stream and transport type are shown in Table A-9.

Table A-9: Internal Methodology's Emissions by Waste Stream and Transportation Type

Waste Stream	On-Road Emissions	Waterborne Emissions
Landfill	227	N/A
Recycling	369	1,437
Compost	191	N/A
Re-use	N/A	N/A

Based on the internal analysis, transportation of Stanford's solid waste totals 2,224 MT CO2e, with 787 MT CO2e attributable to on-road transport, and 1,437 MT CO2e attributable to overseas shipping.

SIMAP

SIMAP's tool automatically includes the transportation of waste in its calculations, based on default data in WARM. Based on the outputs reported by SIMAP, it was not possible to disaggregate transportation-related emissions from treatment emissions.

VitalMetrics

Transportation distances can be customized in the WARM tool, but only on-road miles are taken into account. In their iteration of the WARM model, VitalMetrics employed weighted average roundtrip distances to simplify the process and excluded miles from waterborne shipments. These weighted average distances are reflected in Table A-10.

Table A-10: VitalMetrics Miles Traveled Estimates by Waste Stream and Hauler

Waste Stream	Weighted Average Distance in Miles
Landfill	37
Recycling	41
Composting	84

Unfortunately, the final emissions from transportation cannot be disaggregated in the reporting we received from VitalMetrics, so they are embedded into the treatment emissions provided by VitalMetrics and reflected in the section above.

Wastewater

Tool Inputs

The Wastewater service for all the Stanford historic campus is the City of Palo Alto's Regional Wastewater Quality Control Plant (RWQCP), which uses aerobic wastewater treatment. The Silicon Valley Clean Water (SVCW) treatment facility provides wastewater services for most of Redwood City and performs anaerobic digestion. Stanford's Water Resources & Civil Infrastructure (WRCI) group provided wastewater estimates for the historic campus wastewater production. Estimates for wastewater volume at Stanford's Redwood City campus were provided by Stanford Redwood City's Facilities Operations team. All wastewater volume estimates are reflected in Table A-11.

Table A-11: Wastewater Volume by Treatment Type

Wastewater Treatment	Volume (million gallons, Mgal)
Aerobic Digestion (Main Campus)	402
Anaerobic Digestion (Stanford Redwood City Campus)	22

At the Palo Alto Regional Water Quality Control Plant, aerobic treatment includes preliminary, primary, secondary, and tertiary treatment before it is released to the bay. In preliminary treatment, large solid materials are removed from the wastewater by screens. During primary treatment, the water is pumped into tanks where smaller solids settle to the bottom, or float to the top to be collected for further processing. In secondary treatment, the aerobic decomposition by microorganisms occurs. The water trickles through two-story towers called fixed film reactors, in which microorganisms eat the organic matter in the wastewater. Then, the wastewater moves into another tank for aeration, where bacteria remove ammonia and eventually promote the release of nitrogen gas into the atmosphere. In tertiary treatment, the fine sand and coal filters filter the water even further, before ultraviolet light is used to kill bacteria and viruses without using chemicals.[18]

The Silicon Valley Clean Water (SVCW) treatment facility provides wastewater services for most of Redwood City. This facility employs physical, chemical, and biological modes of treatment to the wastewater. In this process, microorganisms degrade organic contaminants in the absence of oxygen through use of a bioreactor receptable. A bioreactor contains a sludge made of microorganisms that digest biodegradable matter present in the wastewater. The biogas produced as a byproduct of this process is converted into energy.[19] By recovering renewable biogas for energy, SVCW meets up to 70% of the facility's energy demand.

SIMAP/Internal Methodology

SIMAP is the only tool that calculates emissions associated with wastewater. It pulls its emissions factors from the EPA Inventory of Greenhouse Gas Emissions & Sinks.[20] This data is publicly available, so the SIMAP process has been replicated in the internal methodology.

Using Stanford's gallons of water treated under each method, SIMAP applies an emission factor specific to each wastewater treatment type in the units of kg CO2e/gallon. Results in this paper were converted to million gallons (Mgal), as shown in Table A-12.

Table A-12: Wastewater Emissions Factors & Results by Treatment Type

Wastewater Treatment	Emissions Factor (MTCO2e/Mgal)	Total Emissions (MTCO2e)
Aerobic Digestion (Main Campus)	0.43	174

[18] City of Mountain View, Recycled Water: Treatment Process. Illustration on the Regional Water Quality Control Plant. https://www.mountainview.gov/civicax/filebank/blobdload.aspx?blobid=9164

[19] Silicon Valley Clean Water. "Innovation." https://svcw.org/sustainability/innovation/

[20] EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016.

Anaerobic Digestion (Redwood City Campus)	0.47	10

SIMAP estimated Stanford's emissions from wastewater to be 184 MTCO2e for 2019.

Future Considerations

There are some specific methodological improvements that the Scope 3 Emissions Program will continue to research, including:

- Improve tracking of overseas routes traveled and determination of whether one way or roundtrip miles should be used (current methodology uses roundtrip miles).
- For on-road transportation, improve the precision of the emissions factors used based on the exact type of vehicle
- Include transportation emissions associated with reuse programs
- Perform additional research on the landscape of wastewater emissions and whether more recent emissions factors are available
- Improve data tracking for construction & demolition waste to account for the specific material types being discarded
- Improve data tracking for composition of E-Scrap waste to account for the specific material types being recycled
- Improve data tracking for composition of food donations to account for the specific foods being donated. For example, if more meat is donated, meat-specific emission factors could be applied that would increase Stanford's avoided emissions.

Appendix B: Detailed list of Stanford Solid Waste by Stream and WARM Emission Factor Mapping

The first three columns of the table below show Stanford's primary data from its 2019 Annual Diversion Report, compiled by the Waste Systems Program Manager in the Office of Sustainability. The last 3 columns show each waste type's emission factor designation, emission factor (calculated by dividing emissions output by weight input), and total emissions. All emissions are from WARM unless marked * to indicate use of a custom or alternative emission factor, the descriptions for which can be found in the Methodology descriptions under "Solid Waste Tool Inputs." The table below excludes emissions associated with transportation of solid waste.

Table B-1: Volume & Associated Emissions of Stanford's Waste by Material & Waste Stream

Waste Stream	Stanford Waste Material	Weight (Short tons)	Emission Factor Label	Emissions factor (MT CO2e/short-ton)	Emissions (MT CO2e)
Compost	Food Scraps/Yard Trimmings	1,910	Mixed Organics	-0.1	-171
Compost	Stable Waste - Stanford Only	2,226	Mixed Organics	-0.1	-200
Compost	Compost, Redwood City Campus	4	SRWC Annual Composting Tonnage*	-0.1	0
Compost	Brush	71	Branches	-0.1	-4
Compost	Brush to Chips	224	Branches	-0.1	-13
Compost	Logs to Chips	75	Branches	-0.1	-4
Compost	Wood Mixed	61	Branches	-0.1	-4
Compost	Wood Waste	129	Branches	-0.1	-7
Compost	Grasscycling	1,120	Grass	-0.1	-64
Compost	Animal Bedding (Innovive)	119	Yard Trimmings	-0.1	-7
Compost	Yard Trimmings (N)	1,104	Yard Trimmings	-0.1	-63
Compost	Yard Trimmings (Z)	27	Yard Trimmings	-0.1	-2
Compost	Yard Trimmings Mixed	5	Yard Trimmings	-0.1	0
Landfill	PLA	64	PLA	-1.6	-105
Landfill	Mixed Paper (general)	1,849	Mixed Paper (general)	-0.4	-753
Landfill	Single Use Coffee Cups	127	Single Use Coffee Cups*	-0.4	-50
Landfill	Corrugated Containers	436	Corrugated Containers	-0.4	-162

Landfill	Mixed Paper (general) & Food Waste	523	Food Soiled Paper*	-0.3	-178
Landfill	Yard trimmings	111	Yard Trimmings	-0.3	-37
Landfill	Mixed Paper (primarily from offices)	355	Mixed Paper (primarily from offices)	-0.3	-108
Landfill	Landfill, Redwood City Campus	11	SRWC Annual Landfill Tonnage*	-0.1	-1
Landfill	Mixed Organics	97	Mixed Organics	0.0	-1
Landfill	Mixed MSW	474	Mixed MSW	0.0	-2
Landfill	SU: Custom Construction Mix	92	SU: Custom Construction Mix*	0.0	2
Landfill	HDPE	46	HDPE	0.0	1
Landfill	Mixed #3-#7: PVC, LDPE, PP, PS, Other	253	Mixed #3-#7: PVC, LDPE, PP, PS, Other*	0.0	4
Landfill	#1& #2: PET & HDPE	232	#1& #2: PET & HDPE*	0.0	4
Landfill	Mixed Metals	294	Mixed Metals	0.0	5
Landfill	Furniture	172	Furniture*	0.0	3
Landfill	Glass	278	Glass	0.0	5
Landfill	LDPE	723	LDPE	0.0	12
Landfill	PS	75	PS	0.0	1
Landfill	PET	115	PET	0.0	2
Landfill	PP	12	PP	0.0	0
Landfill	Mixed Plastics	161	Mixed Plastics	0.0	3
Landfill	Aluminum Cans	39	Aluminum Cans	0.0	1
Landfill	Electronic Peripherals	48	Electronic Peripherals	0.0	1
Landfill	Carpet	3	Carpet	0.0	0
Landfill	Food Waste	2,394	Food Waste	0.3	605
Recycle	Aluminum Cans	5	Aluminum Cans	-9.1	-45
Recycle	OCC	1,366	Corrugated Containers	-3.1	-4,288
Recycle	Confidential Paper	2	Office Paper	-2.9	-5
Recycle	Supermix/Office Pack	799	Office Paper	-2.9	-2,289
Recycle	UPMG	382	Mixed Recyclables	-2.9	-1,090
Recycle	Styrofoam	0	Mixed Plastics	-2.7	-1
Recycle	Carpet	1	Carpet	-2.4	-2
Recycle	Tin	261	Steel Cans	-1.8	-478

Recycle	Tin Cans	24	Steel Cans	-1.8	-44
Recycle	PET #1	42	PET	-1.0	-44
Recycle	Plastic Caging (Innovive)	130	PET	-1.0	-135
Recycle	Monitors	2	Flat-Panel Display	-1.0	-2
Recycle	Recycling, Redwood City Campus	25	SRWC Annual Recycling Tonnage*	-1.0	-24
Recycle	E-Scrap (Misc.)	8	Mixed Electronics	-0.8	-7
Recycle	E-Scrap	4	Mixed Electronics	-0.8	-3
Recycle	E-Scrap (SU)	126	Mixed Electronics	-0.8	-100
Recycle	CHDPE #2	8	HDPE	-0.8	-6
Recycle	NHDPE #2	7	HDPE	-0.8	-5
Recycle	Mixed Glass	130	Glass	-0.3	-36
Recycle	Clean Fill	52	SU Custom Construction Mix*	-0.1	-4
Recycle	Construction and Demolition	4,488	SU Custom Construction Mix*	-0.1	-378
Recycle	Misc Debris (DM)	1,910	SU Custom Construction Mix*	-0.1	-32
Recycle	Mixed Debris	2,226	SU Custom Construction Mix*	-0.1	0
Recycle	Concrete	4	Concrete	0.0	0
Recycle	Concrete 1	71	Concrete	0.0	-1
Recycle	Concrete 2	224	Concrete	0.0	-1
Recycle	Concrete 3	75	Concrete	0.0	-8
Reuse & Reduction	Clothing/textiles	61	Clothing/textiles*	-22.3	-1,471
Reuse & Reduction	Surplus/Furniture	129	Furniture*	-3.7	-414
Reuse & Reduction	Food Donations	1,120	Food Waste	-3.5	-317
Reuse & Reduction	Animal Feed	119	Grains	-0.6	-592
Reuse & Reduction	Mattress	1,104	Mattress*	1.7	46