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Using a Direct Method to Characterize and Measure Flows of Municipal Solid Waste in the United States

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ABSTRACT
Although there are a myriad of sources of municipal solid waste (MSW) data in the United States, much of these data are not transparent and are also extremely difficult to find. In addition, the two major methods of quantifying national MSW flows—the *BioCycle* State of Garbage in America and the U.S. Environmental Protection Agency (EPA)/Franklin Associates' MSW "Facts and Figures" report—differ greatly in their reported results. This study, sponsored by EPA Region 9 and concentrating on the state of California, shows how an improved method of MSW measurement can be built upon the foundation provided by the State of Garbage in America (SOG) survey and complemented by an in-depth analysis of state data from various sources within a state. The primary goal of this methodology is to provide reliable, transparent, tonnage-based, and readily available MSW data for use by policy-makers, MSW managers, and the general public. California was used as the starting point because of the high volume of data available for that state, as well as the controversy surrounding its unusual method of collecting and reporting recycling rates. Also, because of California's size, its recycling tonnage has a large effect on overall U.S. national figures. It is therefore important to accurately quantify MSW management there. Results show that EPA underestimates U.S. MSW generation rates by a significant amount and that the methodology presented produces consistent and replicable results across different states.

INTRODUCTION
There is a great deal of argument over the best ways to deal with municipal solid waste (MSW) in the United States. Many of these arguments are subjective in nature, a prominent example being the "zero waste" goal often advanced by activists.[1] Although laudable as an ideal endpoint, a closer look at the data suggests that this is far from being achieved in reality. To promote a pragmatic set of policies around MSW management, a better understanding of the amount and characterization of waste produced in the United States is needed. This is the main focus of this paper—the establishment of a transparent methodology that accurately measures flows of MSW in the country. The methodology is demonstrated using California as a test case. An alternative metric to recycling rates was developed by the authors and will be the subject of a future paper.

IMPLICATIONS
An in-depth study of waste management in EPA Region 9 states showed that EPA significantly underestimates MSW generation in the United States, making it difficult to use the agency's tonnage estimates to plan for actual MSW management in practice. A coordinated effort to improve MSW data would go a long way toward reliably measuring and ultimately improving waste management practices in the United States.

EXISTING SOURCES OF U.S. MSW DATA
Currently, there are two major national studies of MSW data in the United States—the U.S. Environmental Protection Agency (EPA)/Franklin Associates' "Facts and Figures," an annual report commissioned by EPA[2]; and the *BioCycle*/Earth Engineering Center (EEC) State of Garbage in America (SOG), a biannual study published by *BioCycle Journal*.[3]

Franklin Associates uses a form of materials flow analysis (MFA) to perform their analysis. However, it is quite difficult to assess the effectiveness of their approach because the specific methodology behind their calculations is not published. A generalized and unpublished description of the original methodology was obtained for this research study.[4] Although the steps taken to calculate MSW flows are not clearly delineated in this document, the underlying methodology is apparent—estimates are based on production data for materials and products that end up in the waste stream, and adjustments are made for imports/exports and for the expected lifetime of materials. The report's bibliography includes many references to the U.S. Department of Commerce, as well as trade organizations like the U.S. Steel Recycling Institute, Battery Council International, etc.

Because collected recyclables are used as feedstock for remanufacturing into new materials, it turns out that the Franklin methodology (which appears to rely on information received from trade/commodity associations) does a good job of tracking the national trends of traditional curbside recyclables (i.e., metal, glass, paper, and plastic [MGPP]). However, it falls short when it comes to organics collection and, more significantly, in its estimate of tonnage of MSW landfilled. For whatever reason, industrial production data do not seem to provide adequate information for estimating disposal tons.

The SOG survey uses an entirely different strategy. Because most states have regulations requiring landfills and waste-to-energy (WTE) facilities to report tons received, it is possible to obtain reasonable disposal tonnage

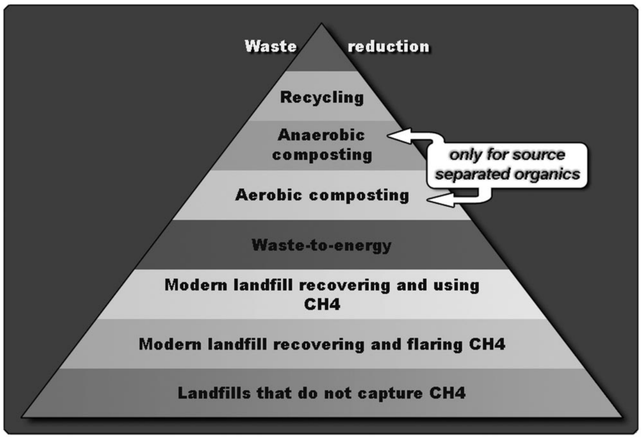

Figure 1. Hierarchy of waste management.

reports from the relevant regulatory authorities in each of the 50 states. Recycling tons are typically not regulated, but the same agencies tend to keep track of these figures as well, although the numbers are generally not as reliable as the reported landfilled and WTE tonnages.

The SOG survey has been conducted since the late 1980s. EEC first became involved in 2003 and developed the current methodology, which focuses on tonnage reports rather than the previous (and more subjective) "percentage estimates" (e.g., percent recycled, percent landfilled, etc.) that were requested in earlier surveys. Detailed questionnaires are sent to representatives of the waste management departments of each state.

The data provided in the SOG survey are thoroughly reviewed by EEC and *BioCycle* researchers. The main goal of this phase of the survey is to allow for an "apples to apples" comparison of states; that is, to adjust reported values to the EPA standard definition of MSW and the hierarchy of waste management (Figure 1). State officials are then contacted again to clarify misunderstandings and fill in missing data where possible. This iterative effort results in a report that characterizes WTE and landfilled tons fairly accurately but still leaves some questions regarding the accuracy of recycling tons. Figure 2 shows a comparison between the SOG and EPA results.

METHODOLOGY DEVELOPMENT

The dramatic differences between the landfilling and recycling tonnages of the SOG and the Franklin reports—first examined by EEC in 2003[5]—highlighted the need for further research on waste management data in the United States. EEC received two grants—one from EPA Region 9 (California, Nevada, Hawaii, and Arizona) and the other from the Aluminum Association, Inc.—to examine the issue in more detail and begin work toward developing a national MSW database to be hosted at Columbia University.

The methodology is designed to be simple, transparent, and replicable, with the assumption that many states and municipalities are already collecting useful data, so it therefore makes little sense to start from scratch. The technique developed can then be summarized in these basic steps.

(1) Use SOG[3] methodology and results as the baseline to populate data for the state in question.

(2) Using EPA Region 9 states, compile and analyze waste data reports published by local and state agencies for the four EPA Region 9 states (California, Hawaii, Nevada, Arizona) to arrive at statewide estimates of waste generation, recycling, and disposal tonnages. Draw conclusions for further action (e.g., delineate needs for further data research).

(3) Perform a materials flow analysis (MFA) for all four Region 9 states using a combination of the direct and indirect methods using production and other published data. The direct (i.e., physical sampling of wastes—in this case using published results) and the indirect (i.e., estimates of waste generation and disposal from economic, industrial, and other data sources) methods are described in *The Practical Handbook*, and variations of it are widely used in the waste data industry (and also by the EPA).[6]

The first step in cross-referencing MSW data from various states is to eliminate (to the extent possible) apparent inconsistencies arising from different methods of collection and reporting. The easiest way to do this is by following the EPA definitions described in the following section.

EPA MSW Definitions

In 1997, EPA published a large document advising state and local governments as to how to measure recycling in their jurisdictions.[7] The goal of this document was to help waste management authorities across the country to publish standardized recycling data that could be compared across regions. The report was based on the expert advice of waste industry and government officials across the United States, and it was hoped that stakeholders would adopt these standards, thus allowing for easier top-down planning of waste systems where appropriate. Although the standards have not been universally adopted, they are generally accepted and were certainly useful for the purposes of this study.

MSW includes solid waste generated by commercial and residential establishments. Common materials included in MSW under this definition are organic waste (food and yard scraps); containers (paper, glass, metal, plastic); other paper products; textiles; and wood. Notable categories excluded under the definition are construction and demolition (C&D) waste and sewage sludge.

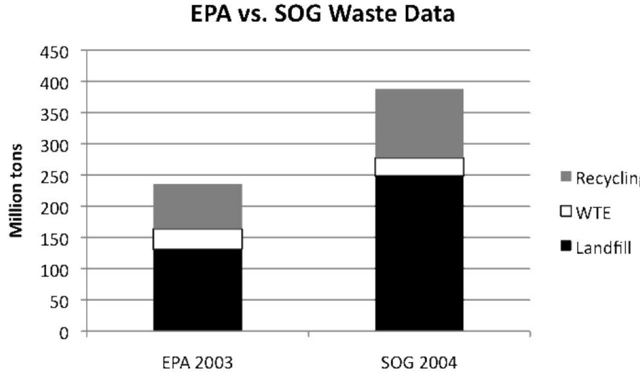

Figure 2. EPA vs. SOG comparison.

Table 1. Derived tonnages of MSW disposal in California.

California 2005 MSW Data	Tons
Disposal (unadjusted)	42,090,000
less C&D	9,133,000
less HHW	126,000
less special waste	2,904,000
Total MSW disposal	29,926,000
MSW to landfill	29,335,000
MSW to WTE	591,000

CALIFORNIA WASTE DATA ANALYSIS

Waste Characterization

California periodically performs waste characterization studies that enable the state to characterize the makeup of waste being disposed in landfills and WTE facilities. California's most recent comprehensive characterization was performed by the California Integrated Waste Management Board (CIWMB) in 2004.[8] The results are used as a reference throughout this study.

Data Analysis

CIWMB is the largest, most comprehensive and complex organization of its kind in the United States. It is "the State agency designated to oversee, manage, and track California's 92 million tons of waste generated each year."[9] Although CIWMB publishes vast quantities of data in online databases and published reports, it is sometimes difficult to track the source of the information. This is particularly the case with recycling tonnages. CIWMB uses a complicated formula in which a base-year waste characterization is applied in combination with disposal tonnages—which are meticulously tracked by the board because its funding is provided by landfilling fees—to arrive at an estimated recycling tonnage. Generally speaking, then, disposal tonnages (landfilled + WTE) are measurement-based whereas recycling tonnages are estimated. In addition, California does not adhere to EPA definitions when calculating recycling tonnages. This has led to an inflated "diversion rate" that may give California an unfair advantage when comparing it with other states.

However, because of the breadth of the research conducted and funded by CIWMB, it is possible to combine the California waste information with the findings of several other CIWMB-published reports to arrive at a reasonable calculation of waste flows in the state. In the first such publication, CIWMB reported that 42,089,545 t of solid wastes were landfilled in the state in 2005.[10] In the previous year, CIWMB released a comprehensive report that used detailed sampling procedures at disposal facilities across the state to statistically determine the composition of California's solid waste.[8] Using that report and the EPA definitions, it was possible to estimate the non-MSW tons that were landfilled in MSW landfills in the state (Table 1). WTE tonnages were derived from the EEC/*BioCycle* 2005 SOG survey and are also listed in Table 1. WTE tonnages were calculated as follows: MSW adjustments were made to California's raw disposal tons on a percentage basis; that is, C&D, household hazardous waste (HHW), and special waste accounted for approximately 29% of the raw disposal tons. This percentage was applied to *BioCycle*'s WTE tonnage to arrive at MSW WTE tonnage.

In 2006, Cascadia Consulting Group and R.W. Beck released a CIWMB-funded report[11] characterizing the residuals from material recovery facilities (MRFs) in California. A total of 390 samples were taken from a representative cross section of MRFs across the state. Using the data reported from these activities, it was possible to back-calculate recycling tonnages that passed through the MRFs.

To incorporate the composting and mulching of organic wastes into this assessment of recycled tonnage, a CIWMB-funded report on California's composting infrastructure was utilized.[12] This report was an attempt to quantify the amounts of organic waste being handled by compost- and mulch-producing facilities in California. The estimated recycling and organics processing tonnages are shown in Table 2.

The methodology used to estimate direct-to-recycler tonnage is as follows. The number of tons of paper recovered in the United States in 2005 was 51 million t.[13] The authors contacted Governmental Advisory Associates to determine the amount of fiber going through U.S. MRFs in 2005 (17.2 million t).[14] The difference was assumed to be U.S. "direct-to-recycler" fiber tons. This amount was then multiplied by California's share of U.S. recycling tonnage, according to the *BioCycle*/Columbia SOG report (20%), to arrive at California's share of U.S. direct-to-recycler fibers of approximately 6.7 million t. It is likely that other materials in the MSW stream (particularly steel) also have direct-to-recycler tons, but those materials could not be accounted for in this study; however, these tons would be significantly less than paper.

Putting all of this information together resulted in the estimate of California's recycling, WTE, and landfilling rates shown in Table 3 and Figure 3.

Comments on California Data

California's Waste Management Act of 1989 (AB 939) mandated a 50% diversion rate by the year 2000. According to CIWMB, this was in fact achieved, and the rate has

Table 2. Derived tonnages of MSW recycled in California in 2005.

Data	Tons
Recycling	
Single-stream MRFs	3,547,000
Multistream MRFs	598,000
Mixed-waste MRFs	1,566,000
Total (MSW) MRF recycled	5,712,000
Direct-to-recycler tons	6,719,000
Total MSW recycling tons	12,431,000
Organics processing	
Composters	4,730,000
Processors	5,138,000
Less ADC	2,100,000
Less agricultural	395,000
Less WWTP	395,000
Total organics processing	6,979,000
Total recycling tons	19,409,000

Notes: WWTP = wastewater treatment plant; ADC = alternative daily cover in landfills.

Table 3. 2005 derived tons of waste generation and disposition in California.

Data	Tons	Percent
Total California recycling	19,409,000	38.9
Total MSW to WTE	591,000	1.2
Total MSW landfilled	29,926,000	59.9
Total California MSW generation	49,925,000	
Per capita MSW generation	1.38	

continued to increase since then; indeed, California's 2005 Diversion rate was reported to be 52%.[15] However, it is important to note that disposal tonnage per capita (mostly landfilling), although decreasing dramatically in the first few years after the law went into effect, has remained flat or increased over the subsequent years. This trend is clearly demonstrated in Figure 4.

It should also be noted that the average U.S. generation rate in 2004, as reported in the SOG survey,[2] was only 1.30 t per capita. Although California enjoys a higher standard of living than some other states, it is simply not credible that its per capita generation of MSW is nearly 100% higher than the rest of the nation.[16] A possible reason for the inflated generation numbers produced by California include the fact that California counts C&D and some other non-EPA-defined waste as part of their MSW stream. Additionally, a study[17] of recycling in New York City showed that many sorted recyclables were unmarketable and were therefore landfilled. This "double-counting" may be responsible for some of the generation inflation in California as well. Finally, it must be assumed that there are faults in the formula CIWMB uses to estimate MSW generation. Figure 5 shows the comparison between California's reported diversion rate and its generation of waste per capita. It is interesting to note that in recent years, the reported rate of recycling and the per capita waste generation increased in nearly identical fashion.

The above is not meant to cast aspersions or downplay the tremendous achievement of California and CIWMB in increasing recycling and composting. In fact, in can be argued that California has led the way in establishing recycling as a mainstream activity through most of the United States. Nevertheless, the CIWMB numbers themselves indicate that, on a per capita basis, California is the nation's major recycler and, at the same time, the largest landfiller.

The point in highlighting this paradox is to bring attention to the fact that, despite the most demanding regulations and targets for recycling, there needs to be (1) integration and analysis of generation and disposition data, and (2) a viable plan for disposing the nonrecycled and noncomposted fractions of the MSW generated.

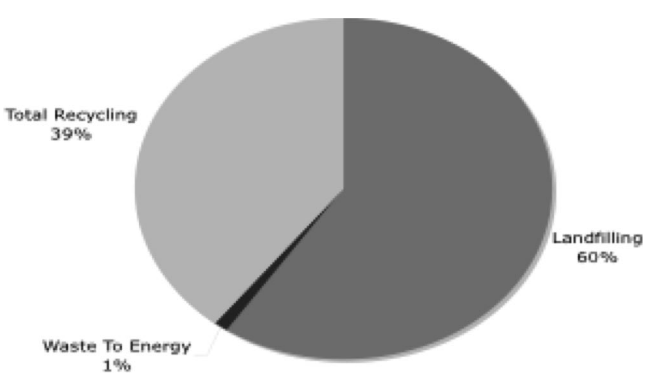

Figure 3. California MSW management.

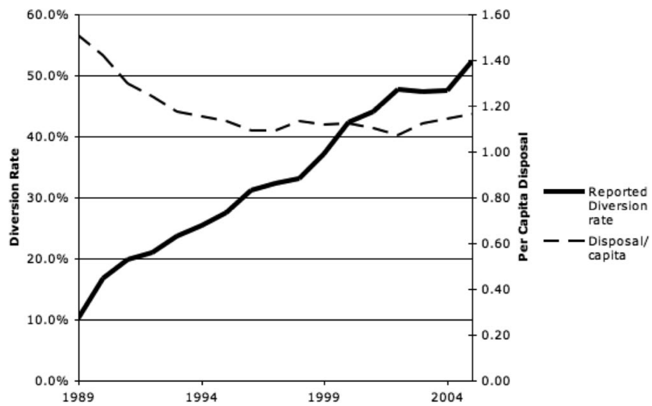

Figure 4. California reported diversion rate vs. reported generation per capita.

CHECKING RELIABILITY OF METHODOLOGY

As mentioned earlier, the methodology was applied to California as an example case in this paper primarily because California has such a wealth of data available. However, the methodology was also used to calculate the MSW flows for other Region 9 states. The most robust data were available for Hawaii and Nevada. Arizona's data have been steadily improving; however, largely because of staffing issues at the state offices responsible for data collection (which have since been resolved), data could not be obtained in time for this study.

Even with only three Region 9 states, a clear picture begins to emerge (Figure 6). Although EPA estimates an average nationwide per capita generation rate of approximately 0.83 t, Region 9 states report a minimum rate of 1.38 t, which agrees very well with results from recent SOG studies.

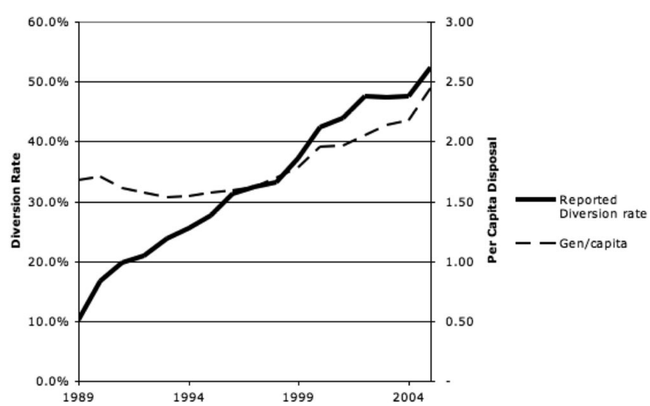

Figure 5. California reported diversion rate vs. reported generation per capita.

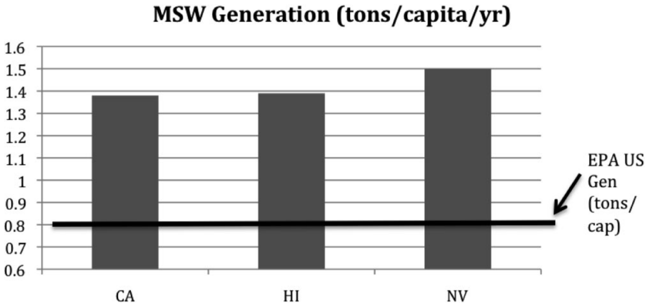

Figure 6. Region 9 test states' estimated MSW generation (tons per capita).

REPORTING AND PRESENTING DATA IN A GEOGRAPHICAL INTERACTIVE DATABASE

After the basic data have been collected, the remaining question is how best to present and disseminate information. The solution reached by the EEC of Columbia University is to develop a computerized "WasteMap" that is a geographic, interactive map of the U.S. MSW Database (MSW-DB), programmed using Adobe Flash. This map is now available on the Web (http://www.wastemap.us).

CONCLUSIONS

This paper has demonstrated the need for compilation and analysis of generation and disposition data at the county and town level. The experience of the authors over the past 5 yr[18] with the SOG, as well as the authors' detailed work with Region 9 and other states, have shown that there are real and measurable differences between EPA-estimated waste data and what is actually occurring in individual states. Unfortunately, because of the lack of sufficient published data on EPA's methodology, it is difficult to quantify the reasons for these differences. However, the authors' detailed study of waste flows in California and other EPA Region 9 states demonstrates the feasibility and relative accuracy of the methodology described in this paper. It is hoped that the methodology will gain more widespread adoption in the form of the MSW database mentioned above.

This study also indicates the inadequacy of recycling targets or "zero waste" as the sole waste management strategy and highlights the importance of quantifying waste flows. Future work at Columbia University will explore existing goals and evaluation systems (e.g., the "goals-oriented" approach to waste management in Austria and other European countries[5]) and determine how and whether they can be adapted for use in the United States. In addition, the authors are working on a metric that would allow users to track progress toward stated goals on the basis of lifecycle assessment. The results of this work will be presented in future papers.

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