Measuring End-Use Technological and Behavioral Waste to Prioritize and Improve Program Design

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ABSTRACT

Energy efficiency potential studies to date have not accurately or effectively measured the potential energy savings that could be obtained through operational and behavioral changes. This is partially because behavioral programs typically have not fully measured the savings opportunities associated with specific behavioral changes, nor have potential studies attempted to quantify the behavioral opportunities by end-use. This lack of measurement has resulted in behavioral programs being placed behind more traditional programs in the program planning process.

This paper details an innovative energy usage and waste study that measures a broad range of baseline practices and quantifies the magnitude of energy waste associated with equipment settings, technology management, and other behaviors. Quantifying both behavioral and technological waste will inform strategic interventions in the market, and can be an effective tool in rendering more savings out of the next generation of energy efficiency programs.

We present the study's approach to quantifying waste due to technological inefficiencies (e.g., lighting, HVAC, consumer electronics) as well as behaviors (including controls and operating procedures) in the commercial and industrial sectors. Specifically, this paper will highlight how the authors 1) collected data necessary to measure how customers interface with a range of end-use technologies and the waste associated with inefficient behaviors, 2) defined waste thresholds (i.e. efficient technologies and behavioral scenarios) using primary and secondary data, 3) identified current usage, and 4) calculated incremental energy use, or waste, due to inefficient technology, equipment settings, and end-user behavior. Finally, the paper discusses how these insights into technological waste, behavioral waste, and their interaction can inform program design.

Introduction

This paper draws upon a study was conducted by Opinion Dynamics Corporation, Vermont Energy Investment Corporation (VEIC), and Mad Dash Field Services for Commonwealth Edison (ComEd). The study covered both residential ComEd customers and commercial and industrial (C&I) sector customers and quantified electricity waste associated with inefficient technologies and behaviors. The focus of this paper is the commercial and industrial portion of the study. In this paper we describe how this unique study leveraged primary data, secondary data, and on-site metering at the end-use and equipment level to allocate total customer usage to various end use categories and measure the share of usage that represents waste in the C&I sector. It also presents examples of how the research team disaggregated energy waste for each end-use and multiple business segments into behavioral and technological waste, and how measuring such waste can unlock new areas of program potential. The approach described here can help identify new opportunities for data collection and measurement, and quantify targetable opportunities for greater behavioral savings.

The goal of this research was to inform ComEd's program planning efforts by identifying gaps in current program offerings and any energy efficient technologies that have achieved sufficient market saturation to warrant exclusion from programs in the future. The behavioral waste analysis further enhances program planning efforts by quantifying end-use specific savings that could be achieved through the adoption of programs designed to promote efficient behaviors. The combined analysis provides energy usage profiles for individual C&I segments and each end-use that disaggregate current energy use into three components: 1) efficient use, 2) energy waste associated with the use of inefficient technologies, and 3) energy waste due to inefficient behaviors. Such insights will be valuable for program implementers nationwide.

Primary Data Collection

The usage and waste analysis focused on the end-uses that account for the majority of electricity use among the ComEd customers within the C&I segments targeted by this study. For each end-use, the research team assessed current electricity usage as well as key categories of technological and behavioral waste. Throughout this study, energy "waste" refers to the amount of electricity that is currently being used, but does not need to be used given: (a) reasonable expectations for equipment upgrades that all customers could make today, and (b) reasonable behavioral or operational changes that customers could make today, and still meet their operating needs. In this analysis, the research team did not attempt to quantify every possible source of electricity waste; rather, we focused on those categories that have the potential to provide significant savings from addressing waste.

The primary data collection activities for this effort included a telephone survey with 1,666 C&I customers, on-site audits at 347 businesses, and lighting and occupancy metering at 70 businesses. Details of the sampling and weighting, data collection, and adjustment methodologies associated with these activities are provided in the full study report and are briefly summarized below.

Telephone Survey

The telephone survey collected comprehensive penetration and saturation data on electricity-using equipment as well as information about customers' use of this equipment, (i.e., their behaviors). The survey was aimed at building owners, business owners, and facility managers with knowledge of energy-using equipment at the business. The research team also used the telephone survey to recruit a subset of survey respondents for on-site audits and metering. The survey was implemented between July 5 and September 12, 2012, and resulted in 1,666 completed interviews. On average, the survey took 22.5 minutes to complete and the response rate was 3.8%.

The survey primarily focused on the end-uses of lighting, cooling, ventilation, refrigeration, motors, office equipment, water heating, compressed air, cooking, and process heating and drying. It also included questions about each business's demographics and important energy characteristics of each facility, such as hours of operation. To maintain a reasonable length, customers were generally only asked about their top four end-uses by annual electricity use. Also, some less frequently encountered end-uses, or end-uses known to be significant for certain sectors, were prioritized for some sectors. For example, we included questions about refrigeration and commercial kitchen equipment in interviews with the grocery and food service segments; office equipment was prioritized in interviews with the office buildings segment; and compressed air and motors were prioritized in interviews with industrial customers.

On-site Audits

The 347 on-site audits were designed to collect data to verify the telephone survey responses and to collect more detailed and technical data that customers are generally unable to report on during a telephone interview. Based on the responses and the verified site data for the same set of customers, adjustment ratios were developed that were applied back to the entire set of survey responses. The research also collected operational schedules and behavioral information from these facilities. The objective of this data collection was to not only gather information about the saturation and penetration of different types of equipment, but also to understand how the equipment is being used and how energy is wasted in C&I facilities. Our team of qualified technicians conducted the site audits between July and November 2012. They entered facility data using tablet computers and a comprehensive Excel-based data collection instrument.

We also used the on-site audits to install lighting monitoring equipment at a subset of 70 sites. These monitoring efforts focused on refining the hours-of-use and waste estimates for lighting, which is the largest electricity end-use. The purpose of this metering activity was twofold: first, to compare the hours of use using logger measurements to the auditor-reported data (and thereby develop factors for adjusting hours of use reported in the telephone interviews), and second, to assess behavioral waste associated with leaving the lights on when the room is not occupied. By deploying a combination light and occupancy loggers, we were able to accomplish both.

We deployed combination light and occupancy loggers in a total of 70 commercial locations. Lighting use and occupancy were metered in each business for an average of 20 days between the months of September and November. For most of these businesses, we deployed loggers in five space types: conference rooms/classrooms, dining areas, hallways/stairwells, offices, and storage areas.

In addition to interior lighting, our on-site data collection covered the following topics:

- Site characteristics
- Building characteristics & envelope
- Business hours
- Lighting
- Electronics - Computers, servers, printers
- HVAC – unitary systems
- HVAC – chillers
- HVAC – air handler system
- HVAC – ventilation
- HVAC – controls
- Motors
- Compressed air
- Other industrial equipment
- Maintenance practices
- Stand-alone refrigeration
- Walk-in coolers/freezers
- Refrigeration systems
- Cooking equipment
- Water heating
- Wastewater treatment

Quantifying Usage and Waste

On the behavioral side, this study aimed to quantify energy consumption in a manner than accounts for how customers consume and manage their energy end-uses, and quantify "waste" attributable to these management practices. Energy studies have largely focused on load profiles with little insight into businesses' discrete behaviors, e.g., the top-down approach. Conversely, those that do focus on end-uses and customer behavior fail to consider how these end-uses add up to consumption profiles, e.g., the bottom-up approach. In both cases, much of customers' waste behavior is lost in the limitations of the method. Rather, the two should be considered together in order to develop a more complete picture of consumption and waste. This study brought together "bottom up" and "top down" approaches to size the potential savings achievable through targeted behavior interventions and the specific end-uses, and to prioritize in program and outreach efforts.

The usage and waste analysis included the end-uses that account for the majority of electricity use among the in-scope C&I customers. Specifically, electricity use and waste were quantified for the end-uses and equipment types show in Table 1.

Table 1: Analyzed End-Uses and Equipment Types

End-Use	Equipment Usage Estimates
Lighting	Interior Lighting
Cooling	Packaged AC, Split AC, Chillers, Room AC
Ventilation	Air handlers and ventilation to outside
Motors	All except motors used for compressed air and those covered by other end-uses (e.g., refrigeration, HVAC)
Refrigeration	Walk-in coolers/freezers, stand-alone cases, display coolers/freezers, vending machines
Office Equipment	PCs, notebooks, servers, imaging equipment, TVs, cash registers
Non-Process Water Heating	Electric hot water heaters

We did not quantify consumption of other known end-uses that we expected to comprise a relatively small portion of overall C&I electricity use. These include: exterior lighting, cooking, space heating, compressed air, process cooling, process heating, industrial processes, and wastewater treatment.

The general approach to estimating current usage, technological waste, and behavioral waste, including adjustments to the use and waste estimates, is provided below. It summarizes the types of technological and behavioral waste included in our analysis, and introduces the graphical representations of usage and waste used throughout this report.

Estimating Current Usage and Waste

The usage and waste analysis for all end-uses begins with an assessment of current electricity use. For each end-use, we developed and applied engineering algorithms to estimate current electricity use as a function of site-specific equipment and behavioral characteristics (for example, efficiency level and hours of use). Our analysis was primarily based on the data collected during site audits, but also utilized a host of information collected through the telephone survey and our metering efforts. Since the primary data collection could not cover all aspects of technology and behavior for all end-uses, the research team often supplemented the primary data with secondary data when necessary. In these cases, wherever possible, information specific to ComEd's customers, e.g., assumptions from the Illinois TRM, or local climate, were used.

After estimating current electricity usage, we then estimated technological waste. For most end-uses, savings opportunities associated with upgrading to more efficient equipment were assessed, where "more efficient equipment" was defined as CEE Tier 3 (if widely available in the market), CEE Tier 2, or the current ENERGY STAR version of equipment.[1] Other types of technological waste could be eliminated by adding additional energy saving measures such as variable frequency drives (VFDs), or demand controlled ventilation. Technological waste can be developed directly, or it can be inferred, e.g., by estimating the electricity usage of an efficient piece of equipment and subtracting that usage from the current usage. In many cases, the research team used the latter approach as the engineering algorithms often contained a term for technology efficiency that could be substituted with a value representing a more efficient level.

Behavioral waste for many end-uses-is associated with longer than necessary run times, either as a result of inefficient temperature setpoints or by having equipment on when not using it (e.g., lights or computers). Other types of behavioral waste vary by type of equipment. Similar to technological waste, behavioral waste can be developed directly, or it can be inferred, e.g., by estimating the energy usage with efficient run times and subtracting that amount from the current usage.

The main C&I energy end-uses and equipment and descriptions of associated technological and behavioral waste included in this study are summarized in Tables 2 and 3, respectively.

[1] Efficient equipment thresholds were aligned with ComEd program guidelines where possible. There were no requirements for cost-effectiveness when defining the efficient case.

Table 2. Technological Waste Categories Included in Analysis

End-Use/Equipment	Description
Lighting	• Upgrade high efficient lighting
Cooling	
Packaged/Split Systems	• Upgrade to new efficient system[a]
Chillers	• Upgrade to new efficient system, according to ComEd incentive qualification standards
Room AC	• Upgrade to new efficient unit, according to ComEd incentive qualification standards
Ventilation	• Installing variable frequency drives in air handling units • Use demand controlled ventilation (where applicable)
Motors	• Install variable frequency drives (where feasible) • Upgrade to new efficient motor
Refrigeration	
Standing Refrigerators/Freezers	• Upgrade to ENERGY STAR unit
Display Cases	• Upgrade to new efficient cases • Install LED lighting (where applicable) • Install occupancy sensors for lighting (where applicable) • Install electronically commutated (EC) evaporator fan motors • Install door heater controls (where applicable)
Walk-In Coolers/Freezers	• Install strip curtains • Install automatic door closers • Install electronically commutated (EC) evaporator fan motors • Install evaporator fan motor control • Allow floating head pressure control • Install door heater controls (where applicable)
Office Equipment	
Computers	• Upgrade to ENERGY STAR laptop • Replace all monitors with ENERGY STAR flat screen monitor
Imaging Equipment[b]	• Upgrade to ENERGY STAR unit
Servers	• Upgrade to more efficient servers • Upgrade computer room air conditioning equipment
Televisions	• Upgrade to ENERGY STAR television
Retail Register	• Upgrade to new efficient units

[a] 15 SEER for systems below 5.4 tons, 12.2 EER for system 5.4-20 tons, 10.6 EER for systems above 20 tons
[b] Imaging equipment includes standalone printers, standalone copy machines, standalone scanners, and multi-function devices

Table 3. Behavioral Waste Categories Included in Analysis

End-Use/Equipment	Description
Lighting	• Turn off lights when not in use for given task • Implement multiple methods of lighting controls
Cooling	• Maintain packaged or split systems regularly (at least every 30 months) • Increase occupied temperature setpoints (77°F for commercial; 82°F for industrial) • Increase unoccupied temperature setpoints (85°F for commercial and industrial)
Ventilation	• Reduce ventilation when not needed based on facility operations and production (industrial sector only)
Motors	• Perform regular maintenance of motors • Maintain or improve efficiency standards for motors through purchasing newer, more efficient motors rather than rewinding
Refrigeration	• Set refrigerators to 38°F and freezers to 0°F
Office Equipment	
Computers	• Turn off or switch to power saver mode when idle • Power down computers outside of business hours
Imaging Equipment[a]	• Optimize power management settings
Servers	• Virtualization (i.e., consolidation) • Power management improvements
Televisions	• Turn off television outside of business hours
Retail Registers	• Turn off register/POS terminal when not in use

[a] Imaging equipment includes standalone printers, standalone copy machines, standalone scanners, and multi-function devices

The magnitude of behavioral waste or technological waste depends on which is addressed first. For example, when behavioral waste is addressed *before* technological waste, changes in behavior are applied to current technology parameters; when it is addressed *after* technological waste, changes in behavior are applied to efficient technology parameters. To allow for flexibility in using the results of this study, behavioral and technological waste were estimated both ways.

Figure 1 helps to illustrate current usage for an end-use and its disaggregation into technological waste, behavioral waste, and "efficient usage," i.e., the residual usage once both technological waste and behavioral waste have been addressed. The larger area of the rectangle (including the shaded portions) represents total current energy consumption for the end-use, which is determined by the energy demand of the installed equipment (y-axis) and the baseline run time (x-axis). Reductions in the area of the rectangle equate to a reduction in usage. The green shaded area across the top of the rectangle along with the "shared waste" rectangle represents the share of current consumption that could be considered technological waste. By switching to more efficient equipment, less wattage is required, and the area of the rectangle is reduced. The blue shaded area on the right side of the rectangle along with the "shared waste" rectangle represents the share of current consumption that can be considered behavioral waste.

By changing behavioral or operational practices in a way that reduces equipment run time, the area of the rectangle is again reduced.

The difference between the two estimates of behavioral waste (and the two estimates of technological waste) can be considered "shared" waste, i.e., waste that is part of either technological waste or behavioral waste, depending on which is addressed first. The remaining (white) area, after technological waste and behavioral waste are subtracted, constitutes the efficient usage of efficient equipment.

It should be noted that the residual, "efficient usage" is only efficient given the waste categories that are included in the analysis. Since there are many sources of waste for every end-use, inasmuch as other categories of waste exist, efficient usage would be further reduced. As such, the estimate of efficient usage could be considered a maximum value.

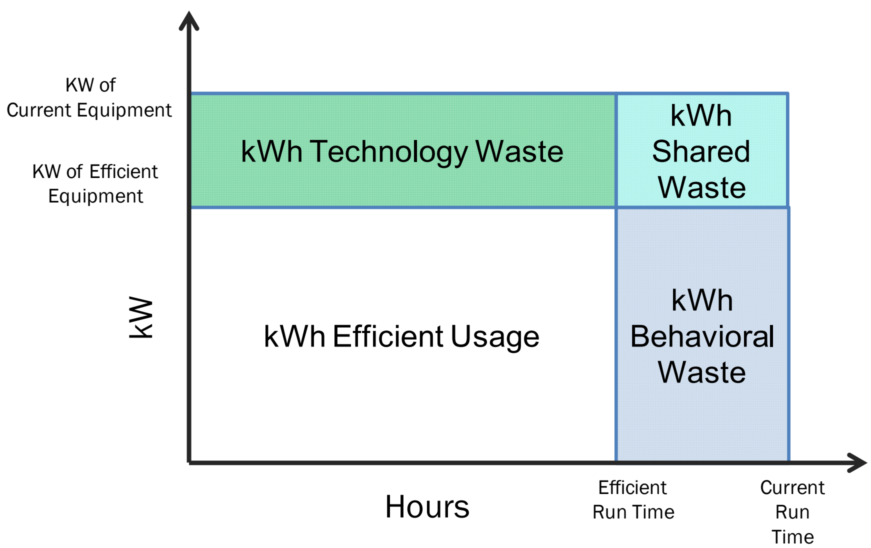

Figure 1. Usage and Waste Diagram Showing Shared Waste

To facilitate assessment of the relative size of these four sources of energy consumption, the study uses pie charts, as shown in Figure 2, instead of the rectangles. However, the terminology corresponds to the concepts presented above.

Building Usage and Waste by End-Use and Commercial and Industrial Segment

For each C&I account in our sample, we estimated annual electricity use of its existing equipment using the methods described above. These estimates were checked against actual customer annual electricity use. Table 4 presents the results of the bottom-up analysis of electricity use by C&I segment.

Table 4. Summary of Electricity Usage of Individual End Use by Commercial Segment and Industrial Rate Class Group

	Total	Total Comm-ercial	Commercial Segment									Total Industrial	Industrial Rate Class		
			Office	Hosp/ Health Svc	Retail	Food Svc	Ware-house	Groc/ Conv	Education	Lodging	Other		<100 kW	100-400 kW	>400 kW
No. of Identifiable ComEd Customers	300,230	168,012	49,531	17,344	21,968	15,184	8,817	4,664	3,136	1,138	46,230	15,675	12,377	2,282	1,016
Usage Summary															
Lighting[a]	28%	31%	30%	32%	49%	17%	37%	25%	33%	27%	29%	17%	28%	18%	13%
Cooling	15%	15%	15%	22%	17%	7%	5%	7%	21%	23%	15%	11%	12%	17%	8%
Ventilation	8%	9%	8%	19%	8%	12%	9%	4%	16%	4%	6%	7%	8%	8%	7%
Motors, Fans, Pumps	13%	7%	3%	4%	5%	5%	2%	7%*	7%*	7%*	14%	38%	37%	42%	47%
Refrigeration	6%	6%	1%	1%	3%	40%	3%	24%	5%[+]	2%	5%	1%	3%[+]	1%[+]	0%
Office Electronics	9%	10%	21%	12%[+]	4%	2%	5%	1%[+]	6%	5%	5%	3%	9%	3%[+]	2%[+]
Non-Process Hot Water	0.4%	0.4%	0.5%	0.4%	0.2%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%	0.2%	0.9%	0.2%	0.2%
All Other	21%	22%	21%	10%	13%	16%	39%	32%	12%	32%	25%	23%	2%	11%	23%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Note: values may not sum to 100% due to rounding
* End-use percentage defaults to sector average due to low sample size
[+] At least 1 type of equipment within end-use defaults to sector average due to low sample size
a=Interior lighting only

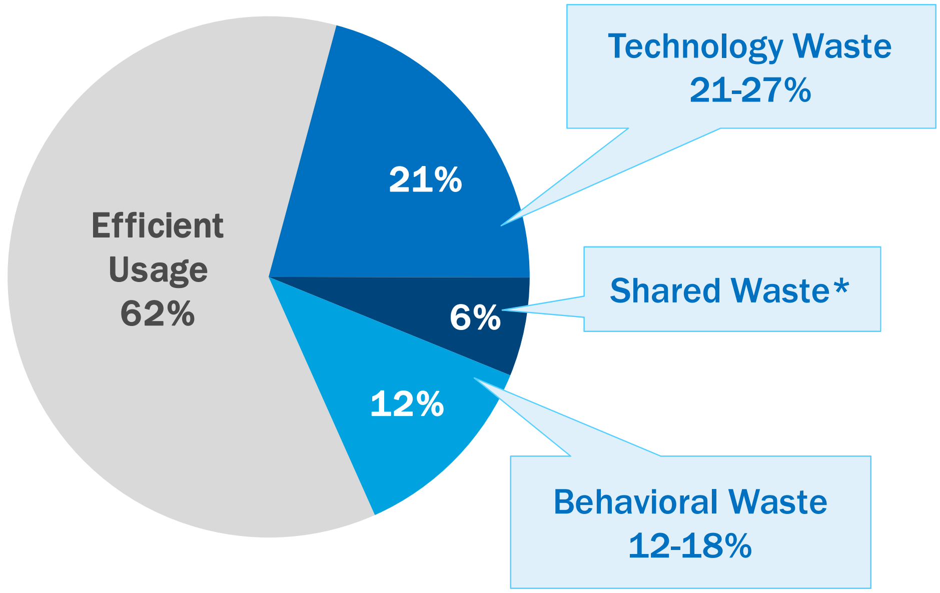

Figure 2. Usage and Waste Pie Chart

Table 5 presents the usage and waste results, across all analyzed end-uses. In general, office equipment, refrigeration and lighting show the greatest opportunities to reduce technological waste by upgrading to newer, more efficient equipment. Technological waste accounts for 42%, 38% and 35% of current usage for these end-uses, respectively. Lighting also has the greatest opportunities to reduce behavioral waste, which accounts for 36% of current usage, mainly by improving and optimizing lighting controls.

Table 5: Summary of Usage and Waste Results

	Analyzed End-Uses					
	Lighting	**Cooling**	**Ventil-ation**	**Refriger-ation**	**Motors**	**Office Equipment**
% of C&I Usage	28%	15%	8%	6%	13%	9%
End-Use Penetration	100%	64%	82%	25%	32%	93%
kWh Per Business *(with End-Use)*	36,394	29,781	13,475	39,863	54,049	22,433
kWh Per Business *(All In-scope Businesses)*	36,394	19,199	11,018	7,181	20,482	11,311
Total Annual MWh	10,926,461	5,764,059	3,308,014	2,155,858	5,117,542	3,395,989
% Efficient Usage	42%	63%	89%	59%	94%	42%
% TW (before BW)	35%	29%	11%	38%	6%	42%
% BW (after TW)	23%	9%	0%	3%	0%	16%
% BW (before TW)	36%	12%	0%	8%	0%	23%
% TW (after BW)	23%	26%	10%	33%	6%	35%
MWh TW (before BW)	3,802,392	1,661,246	353,309	818,900	291,991	1,417,598
MWh BW (after TW)	2,543,488	497,550	15,149	72,681	16,433	563,814
MWh BW (before TW)	3,882,878	682,822	17,031	181,816	17,631	797,457
MWh TW (after BW)	2,463,002	1,475,974	351,426	709,765	290,793	1,183,955

Source: ComEd Usage and Waste Analysis

Conclusion

The study utilized an innovative approach to concurrently analyze technological and behavioral waste by end-use for commercial and industrial sectors. The results of this study will be used by ComEd portfolio and program managers to inform the program planning process and to identify strategic interventions in the efficiency market. The results will help to identify pockets of energy-savings opportunities within C&I segments and energy end-uses, as well as gaps in program offerings. By quantifying technological waste as a function of currently-installed equipment, the results of the study can be used to identify measures that may not need to be screened for future programs. By quantifying technological and behavioral waste together, this approach can be used to identify potential behavior-based components to incorporate into existing technology-based programs. Similarly, the results can help to inform decisions on how best to apportion resources between behavioral and technology-based programs.

In addition to program planning at an equipment or end-use level, the waste findings can be used to identify customer segments with high savings opportunities and thereby allow Program Managers to more effectively target marketing of programs or measures. The segments of interest may be existing segments, such as the Commercial and Industrial business types and rate classes described above. The data could also be “cut” on other segments or dimensions, such as facility ownership (own/rent), managed account status, facility size, or customer rate class.

These cuts could reveal pockets of low or high waste overall or by end-use, including behavioral waste. Taking the idea of targeting or segmentation further, predictive analysis such as clustering or segmentation analysis could be performed, to determine if facilities with high waste for a particular end-use share any targetable characteristics that program managers could use to identify specific businesses that might benefit from utility programs. For example, ComEd suspects there are significant savings opportunities within the small business sector and is hoping to grow its program aimed at this customer segment. The ability to parse the usage and waste data by measure and customer category will allow the implementation team to identify promising savings opportunities and to develop programmatic strategies that address these opportunities.

The many potential applications and cuts of the usage and waste findings speak to the study's flexibility. The deep end-use profiles, that incorporate actual, site-specific information on equipment, efficiency levels, and operations, provide a thorough understanding of where electricity is going and where it's being wasted – down to the end-use, equipment, and segment. The bottom-up nature of the analysis, with waste indicators and estimates for individual facilities, provides a platform for flexible targeting and segmentation analysis. The analysis approach also allows waste to be calculated using different "thresholds" or definitions, to examine opportunity if, for example, we assume different thermostat setback scenarios.

The waste findings provide unique information that is complementary to standard potential studies. By quantifying waste at a point-in-time that is not constrained to current cost-effectiveness inputs (e.g., avoided costs) or past measure uptake rates, this study illustrates how much energy is currently being "wasted", per a set of reasonable upgrades and behavioral change assumptions. While other information may need to be overlaid onto these results determining whether to pursue specific opportunities identified by this study, the deep end-use level analysis provides a comprehensive starting point for these discussions.

This unique approach can provide considerable benefits to comprehensive planning of efficiency programs, particularly for C&I programs, which often do not have behavioral components, and for which behavioral waste is rarely quantified. Whether broad-based or targeted, the usage and waste approach described here can be an effective tool in rendering more savings out of existing programs and for guiding the next generation of energy efficiency programs.