Electronic Products Generation and Recycling Methodology Review
U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery
December 2016

1.0 Background

The Environmental Protection Agency's (EPA's) Sustainable Materials Management (SMM) report series[1] estimates the quantity of selected electronic consumer products ready for end-of-life (EOL) management and the quantity of those products collected for resale or materials recycling.

Consumer electronic products included in the EPA report series are electronic products used in residences and commercial establishments such as businesses and institutions and are categorized as video, audio and information products. Video products included cathode ray tubes (CRT), televisions (TVs), flat panel televisions, projection TVs, videocassette recorder (VCR) decks, camcorders, laserdisc players and digital versatile disc players (DVD). Audio products included rack audio systems, compact audio systems, portable compact discs (CD), portable headset audio, CD players and home radios. Information products included cordless/corded telephones, mobile telephones, telephone answering machines, facsimile (fax) machines, desktop and laptop computers, computer printers and other peripherals, computer monitors, keyboards, and mice. Certain other electronic products such as separate audio components were excluded from EPA's measurement because of data limitations.

EPA's consumer electronic generation is estimated by applying a Sales Obsolescence Method (SOM) to historical sales. EPA applies lifespan assumptions to historical annual apparent consumption (i.e., sales). Apparent consumption equals single year U.S. manufacturer shipments plus U.S. imports minus U.S. exports. The year in which a particular electronic item is ready for EOL management is determined from the estimated lifespan of the item. Consumer electronics are owned by a user for two to over 20 years, depending on the product and assumptions made about time in use and storage.

The purpose of this analysis is to review lifespan and other parameters used by EPA in 2015 to estimate used consumer electronic product generation with those used by the Solving the E-waste Problem (StEP) Initiative and summarized in a published report.[2] This StEP Initiative report was preceded by a report characterizing various methods of flows of used electronics including generation, recovery, and export (Miller, et al., 2012). The StEP Initiative is an international consortium of stakeholders created to address E-waste issues.

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[1] U.S. EPA. Advancing Sustainable Materials Management: Facts and Figures, formerly Municipal Solid Waste (MSW) in the United States: Facts and Figures report series located at https://www.epa.gov/smm/advancing-sustainable-materials-management-facts-and-figures-report

[2] Parameters used by the StEP Initiative and provided by the authors of: Duan, H., Miller, T.R., Gregory, J., Kirchain, R., Linnell. J. 2013. *Quantitative Characterization of Domestic and Transboundary Flows of Used Electronics Analysis of Generation, Collection, and Export in the United States*. MIT Materials Systems Laboratory (MIT MSL) and National Center for Electronics Recycling (NCER) under the umbrella of the StEP Initiative.

EPA comparison analysis of EPA and StEP Initiative report product lifespan, distribution, and weight assumptions are presented in this document for a subset of EPA's defined consumer electronic products and include desktop computers, laptop computers, mobile telephones, CRT TVs, flat panel TVs, and projection TVs. In addition to the generation methodology comparison, a comparison of estimated consumer electronics recycled by EPA and the StEP Initiative methods is presented.

EPA also attempted to determine what percentage of recycled electronics were processed by certified versus uncertified organizations. Finally, this memorandum includes a scoping effort to judge the availability of data to estimate recycling rates by individual electronic products. This initial effort focused on mobile phones and is presented in Appendix C.

Throughout this document the use of the term EPA's 2015 model refers to the 2015 methodology used to estimate consumer electronics generation for the SMM report series. The use of the term StEP Initiative refers to the approach and parameters used in the 2013 StEP Initiative study cited above as provided by the study authors for this analysis. The analyses presented in this memo used many but not all of the parameters used in the StEP methodology therefore results may differ.

2.0 Generation Methodology

The SOM is a commonly used approach for estimating when a product sold in a given year will be ready for EOL management (generated) which means it is either ready to be collected by a used electronics processing organization for reuse (with or without refurbishing), materials recycling, or sent to combustion with energy recovery or landfilling. Before an electronic item is generated, it may be used by one or more people, and it may be stored in a home or business. This period of use and storage is considered its lifespan in this document. Generation does not include electronics that are passed amongst family members and friends or co-workers, or sold informally in person or over the internet by individuals.

This analysis uses SOMs to estimate residential and commercial desktop and laptop computers and mobile telephone generation. To calculate TV generation, the SOM does not distinguish between residential or commercial sources.

There are three pieces of information needed in order to estimate the quantity of generated electronics in a given year by the SOM method: (i) the sales of the electronic products over time; (ii) the probability distribution of product lifespan, which is the expected time electronic products remain in use or storage in a home or business before generation and ready for EOL management; and (iii) the weight of individual products. Section 2 discusses and compares the data and parameters used by the SOM for estimating electronic product generation.

2.1 Historical Sales Data

This analysis used the same historical sales data when comparing the different lifespan, distribution, and weight parameters between EPA's model and the StEP Initiative. Sales data can be purchased from various market research companies and can differ slightly between companies. EPA's 2015 model and the StEP Initiative use similar sourced historical sales data, and a review of the two datasets revealed very small differences. It was determined that these differences would not impact the final results; a comparison of the datasets was not included in this analysis. The parameters – lifespan, distribution method, and weight – are bigger generation estimate drivers.

The National Center for Electronics Recycling (NCER) provided the historical sales data used in this analysis for desktops and laptop computers and mobile telephones. The data differentiates between residential sales and those from commercial sales from businesses and public agencies. The breakdown of sales by these two purchasing sectors allows for different lifespan assumptions, where data are available, and a direct comparison of results generated by EPA's 2015 model and the StEP Initiative model. Tables 1, 2, and 3 show the NCER sales data used to estimate 2013 generation of desktop and laptop computers and mobile telephones.

Table 1. Desktop Computer Sales (1,000 units)

Year	Residential Consumer	Business/ Public	Total
1993	4,883	8,138	13,020
1994	5,738	9,563	15,300
1995	6,912	12,228	19,140
1996	7,567	14,854	22,421
1997	9,314	17,453	26,767
1998	11,981	20,545	32,526
1999	16,375	23,113	39,488
2000	17,475	23,347	40,822
2001	13,575	21,517	35,093
2002	13,941	21,305	35,245
2003	15,238	21,956	37,194
2004	15,651	22,807	38,458
2005	15,100	23,242	38,342
2006	13,459	21,959	35,419
2007	11,743	22,470	34,212
2008	9,744	21,619	31,363
2009	10,455	18,318	28,772
2010	10,172	18,708	28,880
2011	9,081	18,199	27,280
2012	8,497	17,174	25,672

Source: National Center for Electronics Recycling, 2014.

For years with zero data (Table 2 Laptop computers sales), the Step Initiative model assumes zero sales; EPA's 2015 model assumes a shorter lifespan so sales data prior to 2005 are not included in the generation calculation for the year 2013. Lifespan parameters are discussed in section 2.2.

Table 2. Laptop Computer Sales (1,000 units)

Year	Residential Consumer	Business/ Public	Total
1983-1991	0	0	0
1992	148	1,702	1,850
1993	202	2,326	2,528
1994	256	2,944	3,200
1995	582	2,982	3,564
1996	610	4,339	4,949
1997	517	5,484	6,000
1998	572	5,836	6,408
1999	1,319	6,552	7,871
2000	1,740	7,333	9,073
2001	1,836	7,139	8,975
2002	2,941	6,819	9,760
2003	4,553	7,754	12,307
2004	5,446	9,151	14,597
2005	7,586	11,638	19,224
2006	10,812	13,340	24,152
2007	14,319	15,590	29,909
2008	18,601	15,522	34,123
2009	27,983	14,562	42,545
2010	29,915	16,471	46,386
2011	27,337	16,933	44,270
2012	24,746	15,629	40,375

Source: National Center for Electronics Recycling, 2014.

Table 3. Mobile Phone Sales (1,000 units)

Year	Residential Consumer	Business/ Public	Total
2002	58,740	63,560	122,300
2003	70,488	69,512	140,000
2004	76,951	65,791	142,742
2005	96,074	53,933	150,007
2006	116,927	48,199	165,126
2007	128,379	53,549	181,928
2008	128,240	47,178	175,418
2009	134,321	45,671	179,992
2010	125,954	57,235	183,189
2011	154,618	36,196	190,814
2012	147,098	27,634	174,732

Source: National Center for Electronics Recycling, 2014.

Television sales shown in Table 4 are those data used by EPA's 2015 model to estimate generation. Prior to 2010 the data are from the U.S. Census Bureau and *Appliance Statistical Review*. Beginning in 2010, the data are market data compiled by NPD Group US Technology Consumer Tracking.

Table 4. TV Sales (1,000 units)

Year	CRT TV	Flat Panel TV	Projection TV
1989	26,025	891	295
1990	23,117	822	372
1991	20,843	803	391
1992	23,773	904	443
1993	24,578	887	485
1994	21,533	750	542
1995	19,349	718	669
1996	25,230	979	981
1997	27,475	1,089	1,161
1998	28,433	1,029	1,362
1999	27,819	983	1,455
2000	24,724	836	1,680
2001	22,639	852	1,958
2002	26,932	1,111	2,653
2003	26,066	1,498	2,809
2004	24,930	9,593	3,607
2005	22,295	5,400	2,965
2006	16,982	20,558	3,064
2007	6,348	29,126	1,961
2008	1,324	32,985	1,594
2009	476	36,845	1,228
2010	175	40,704	861
2011		42,372	921
2012		42,414	925

Source: EPA consumer electronics methodology, 2014.

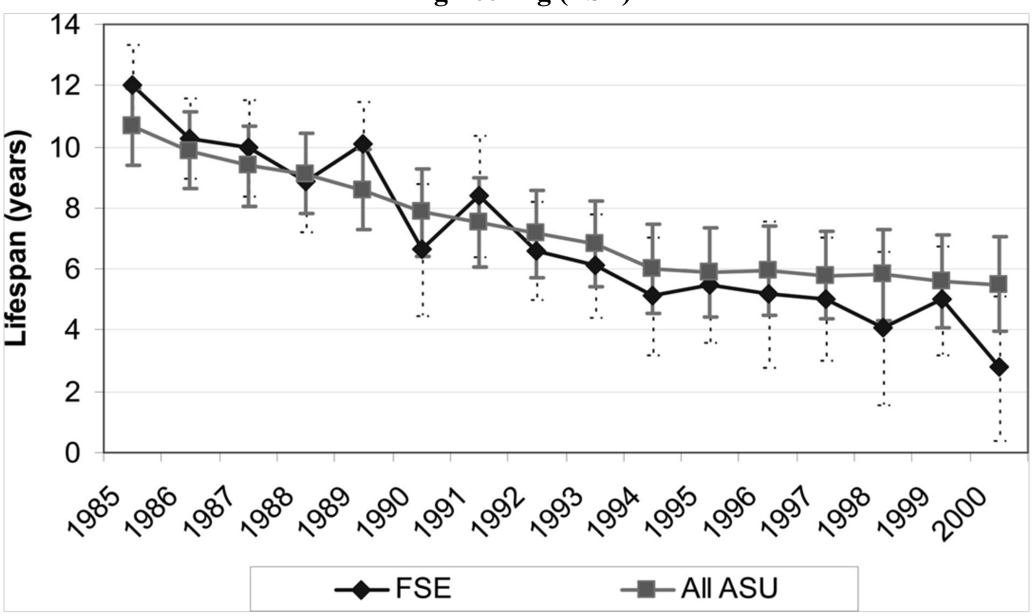
2.2 Product Lifespan

Individuals have different habits with regards to their use and storage of electronics in their home or place of work, and each type of electronic remains useable for a different length of time. Due to the complexity of habits and electronics usability, instead of estimating an exact lifespan, a range of possible lifespans is estimated. The probability distributions used to represent this range are described in the section 2.3.

As technology and user habits change, the general expectation is that the average lifespan of electronics will decrease. Researchers at Arizona State University studied institutionally owned computers at their university and demonstrated a decreasing average time of institutional computer ownership compared to the year purchased (Babbitt, 2009). Figure 1 shows that personal computers purchased by the university in 1985 had an average lifespan of 10 to 12 years at the university compared to an average between two and six years for computers purchased in 2000.[3]

Advanced models can attempt to take this into account by creating different ownership lifespans for each year of sale, but most do not. Most literature has not addressed this across all consumer electronic owner types; there may be differences among residential owner habits as compared to institutional owners.

Figure 1: Mean Lifespan of Institutional PCs at ASU and the Fulton School of Engineering (FSE)



Source: Reprinted with permission from Babbitt, C., Kahhat, R., Williams, E., & Babbitt, G. 2009. Evolution of Product Lifespan and Implications for Environmental Assessment and Management: A Case Study of Personal Computers in Higher Education. Environmental Science & Technology, 43(13), 5106-5112. Copyright 2009 American Chemical Society.

[3] A follow-up study showed that in 2008 the average lifespan for desktops managed by the Surplus Property office at the same institution was 7.4 years (Babbitt, 2011). This may be due to increasing durability and thus extended life of PCs, or the characteristics of the desktop subset managed by that office. This example demonstrates challenges in obtaining consistent lifespan estimates.

There are three basic approaches to arrive at estimated lifespans:

1. survey users or electronics asset managers to determine their habits
2. sample the age of electronics when they are generated
3. derive estimates from a body of literature on the subject

There are a few useful criteria to compare these approaches. The electronic products analyzed should be representative of habits of residential and commercial users across the country, since national sales statistics are used. It should be feasible to periodically collect more data to update prior estimates, given ever-changing technology and user habits. Since the range of possible lifespans will be applied to the entire sales volume for a given year using SOM, ideally the approach can estimate the lifespan of both the electronics already generated and those yet to be generated.

For the first approach, by using surveys, residential respondents can be selected to be demographically and geographically representative of the country, and asset managers or small business owners can similarly be selected to reflect businesses using such electronics. In this way, their responses can be expected to reflect the habits of all users in the country. Information about the condition at purchase, the time in use and time in storage of multiple types of electronics can be gathered at once allowing for a greater understanding of total electronics product ownership. EPA's 2015 SOM relies on this user input method to estimate product lifespans for commercial desktop and laptop computers using Federal Electronics Challenge (FEC) participant reported data. The StEP Initiative relies on residential survey data to develop product lifespan assumptions for residential desktops and laptops.

In the second approach, by capturing data on used electronics when they are generated through sampling, the exact age can often be known, whereas the accuracy of responses from survey respondents relies on their memory. Data for about 9,500 products collected by a U.S. used electronics processor from late 2007 to late 2009 were analyzed and the age was determined; the results can be seen below in Table 5 and in Figure 2. The product histograms in Figure 2 plot the data from years 1 through 30.

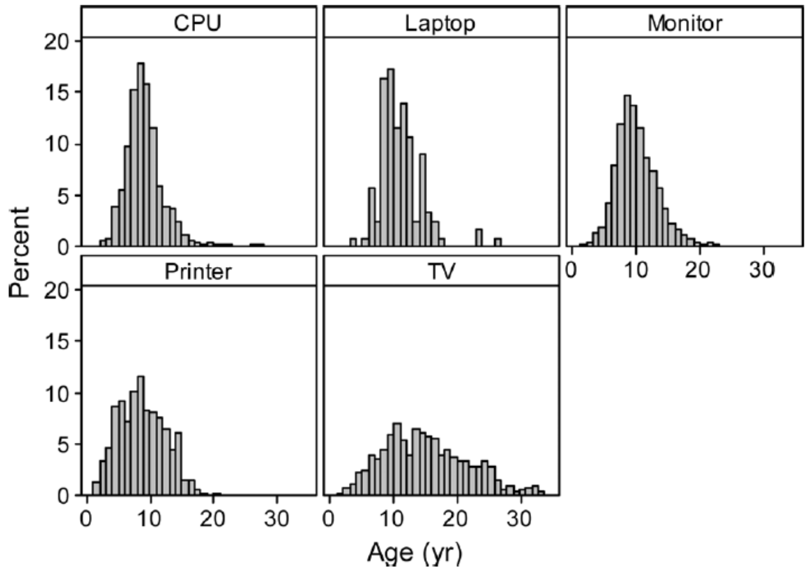
Table 5. Descriptive statistics for age (years) of electronics collected by U.S. processor from 2007 to 2009

Product Type	Mean	Standard Deviation	Minimum	Median	Maximum
CPU	9.16	3.05	1.92	8.82	27.72
Laptop	11.10	3.39	3.10	10.46	26.67
Monitor	9.95	3.24	1.24	9.48	29.44
Printer	8.73	3.61	1.13	8.47	20.24
TV	15.21	6.70	1.56	14.49	33.91

Source: Data reprinted with permission from Kwak, M., Behdad, S., Zhao, Y., Kim, H., & Thurston, D. "E-Waste Stream Analysis and Design Implications." Journal of Mechanical Design. Vol 133(10), 2011. Copyright 2011 ASME.

There are several downsides of this approach. First, it is very difficult to capture this data for electronics that are sent to combustion with energy recovery or landfilling, which have a different lifespan. Second, getting data from a diverse sample of used electronics processing organizations is challenging. Finally, it does not capture electronics yet to be generated, and information about use and storage habits and other electronics ownership habits cannot be captured.

Figure 2: Histogram of Age for Different Product Types Collected by US Processor from 2007 to 2009

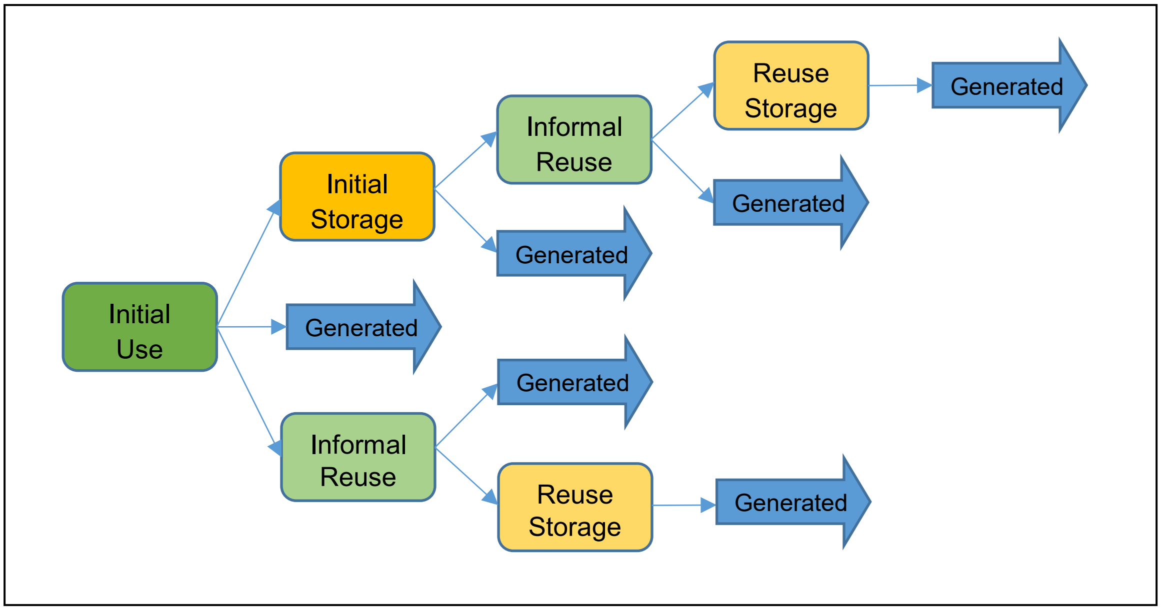


Source: Reprinted with permission from Kwak, M., Behdad, S., Zhao, Y., Kim, H., & Thurston, D. "E-Waste Stream Analysis and Design Implications." Journal of Mechanical Design. Vol 133(10), 2011. Copyright 2011 ASME.

In this analysis, the StEP Initiative approach incorporated lifespan parameters for institutionally managed products from the Arizona State University at their EOL in 2008 for commercial desktops and laptops (Babbitt, 2011). This was done due to insufficient commercial survey data.

Regarding the third approach, many authors have addressed the issue of electronic product lifespans, but each with a different estimation method and varying scope in terms of products, historical time period, and geographic region. A combination of survey and EOL sampling studies are often combined in published literature. EPA's 2015 SOM relies on this method to estimate product lifespans (for all products except commercial desktop and laptop computers) published in the SMM report series. The StEP Initiative uses published data to estimate product lifespans for mobile phones and TVs by incorporating estimates into a model which assigns probability to different pathways to generation. As can be seen in Figure 3, StEP Initiative considers six different pathways. All pathways start with initial use by the first owner followed with a combination of initial storage, informal reuse, and reuse and storage by the second owner. The likelihood of each step along the path, along with the typical length of that step, is found by combining probabilities inferred from several published studies. Those likelihoods and lengths are combined and a Weibull probability distribution is fit to them. This method is a refinement of the model developed by Matthews, McMichael et al. (1997).

Figure 3: Possible Initial Use, Storage, and Reuse Pathways to Generation



To address the deficiencies in each approach, ideally, multiple approaches would be periodically attempted in order to compare how close estimates are and utilize a bounded range of estimates.

Once the lifespan data are collected, the next step is to derive or assign a probability to each lifespan within the range of possible lifespans. This is captured in a probabilistic distribution (probability density function). The lifespan parameters used by EPA's 2015 model and the StEP Initiative for the products included in this analysis are included in section 2.3.

2.3 Lifespan Probabilistic Distribution

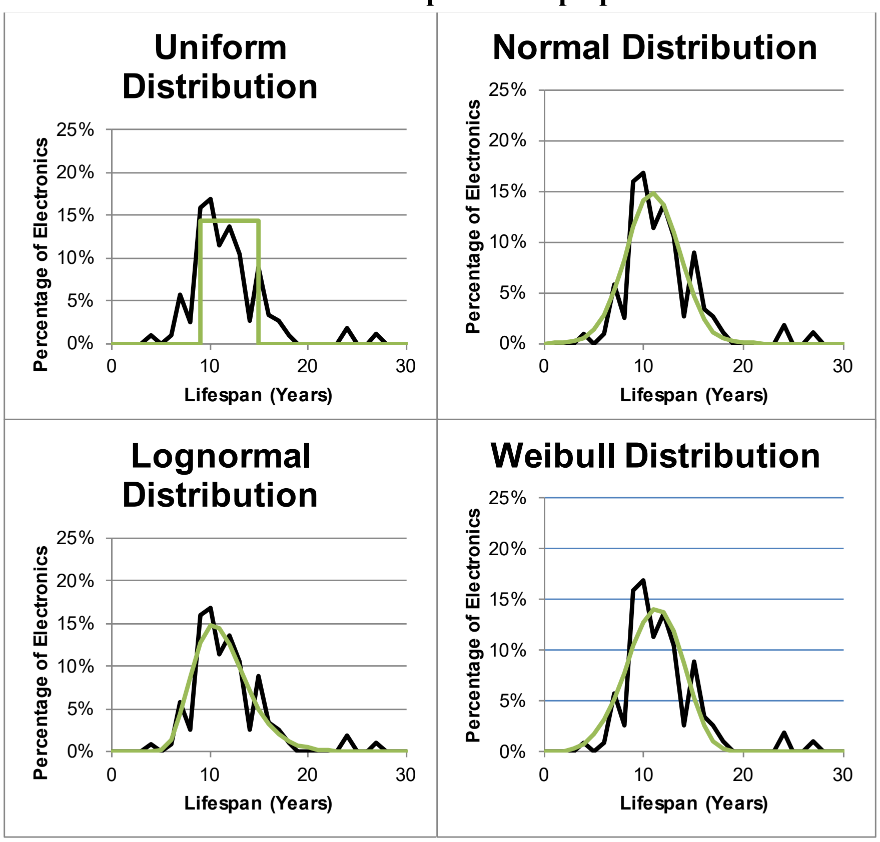
The simplest probabilistic distribution is a Uniform Distribution. The Uniform Distribution predicts that for an electronic bought in a given year, it will be generated (reach EOL) at year three to year 11 from the date of purchase and the same number of electronic products would be generated annually in year three through 11 of its life. In other words, the same number (1/9 of the sales volume) of the electronic would be generated in each of those nine years.

A second method is using a bell curve, or Normal Distribution, which predicts that most of the electronics will be generated for example seven years after they are sold, with fewer being generated before seven years and that same amount being generated after seven years. Many phenomena follow a Normal Distribution and it is widely used in many fields. One challenge is that it will also predict that some small number of electronics are generated before they are sold which does not make physical sense and will lead to a small amount of error in the estimate.

A third approach is using a Lognormal Distribution, which will not predict that any electronics are generated before they are sold, but will predict a few more are generated far into the future than a Normal Distribution.

A final approach is the Weibull Distribution, which is shaped somewhat similarly to the Lognormal Distribution, but has a different underlying meaning and different parameters (shape and scale versus mean and standard deviation). The Weibull distribution is typically employed to look at systems where there are components that fail or censor over a period of time. For example, a machine that breaks down is considered to have failed. A machine that doesn't break down is considered to be censored. The Weibull distribution parameters (fail and censor) are well-suited for analyzing surveys of used electronics habits, assigning fail status to an electronic product generated for EOL management. A substantial benefit to fitting survey data to a Weibull distribution is that it can capture those electronics that were purchased in a given year, but not yet generated at the time of analysis (censored). Survey respondents were asked not only about the electronics they generated, but about electronics, which they purchased but have not yet generated. One cannot know for certain which year into the future those electronics will be generated, but the analysis underlying a Weibull distribution can estimate it. For this reason, analyses resulting in Weibull distributions will often predict longer lifespans than analyses based only on generated electronics. Figure 4 shows the four best-fit probabilistic distributions applied to the laptop collection data shown in Figure 2. Green lines indicate distributions, while black lines present the percentages of laptops with different lifespans.

Figure 4: Example Uniform, Normal, Lognormal, and Weibull Distributions to Model Possible Lifespans of Laptops



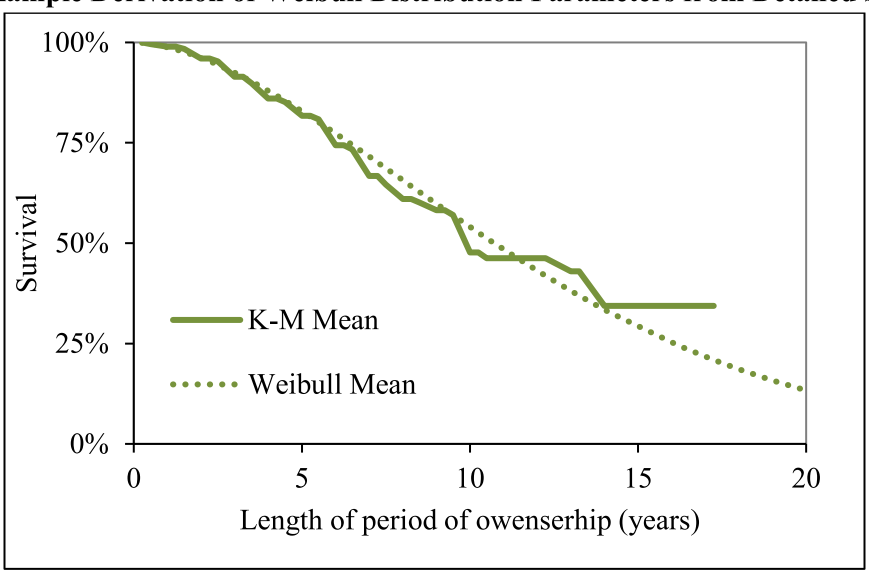
Source: Example distributions applied to laptop data shown in Figure 2.

Both EPA's 2015 model and the StEP Initiative assume a constant lifespan per electronic product for each year of sale. However, EPA's 2015 model uses uniform distributions to form its SOM for used electronic products based on combining estimates from published literature and FEC participant input data. In practice, the model takes an average of the sales volume of an appropriate range of years prior to generation. For example, EPA's 2015 model assumes that a residential desktop computer has a uniformly distributed lifespan from three to 12 years. The annual sale volumes from 2001 to 2010 are averaged, to estimate the generated volume in 2013.

The StEP initiative uses Weibull distributions to model the lifespan of residential used computers and computer monitors based on detailed, nationally representative surveys. Each device reported in the survey was coded as still owned by user ("censored") or no longer owned by user ("failed"). An approach called survival analysis is used to derive the Weibull distributions. The analysis presented in this document also uses Weibull distributions to model the lifespan of the other electronic products based on published data.

Figure 5 presents the mean residential laptop Kaplan-Meier (K-M) Survival Curve which shows the percent of products that have "survived" (i.e. not "failed") after a given year, taking into account those which are still owned by user ("censored"). The smooth dotted line is the result of a Weibull regression. The parameters from that curve are used to define the Weibull distribution. This information was merged with estimations about subsequent reuse to arrive at an overall lifespan distribution; details can be found in (Duan, et al., 2013). Since informal reuse before generation is a small fraction of the products, excluding it does not have a large impact on generation estimates.

Figure 5: Example Derivation of Weibull Distribution Parameters from Detailed Survey Data



As with the other distributions, one can also find a best-fit Weibull distribution to data that is not derived from survival analysis of surveys. The StEP Initiative method fit Weibull distributions to the lifespan lengths and probabilities derived from literature as described above. Notably, the United Nations University recently published Weibull distributions for all used electrical and electronic products, based on a mix of detailed data gathered in several European countries (Baldé, et al., 2015) using a method described in Wang, et al., (2013).

Table 6 shows the lifespan parameters used by EPA's 2015 model and the StEP Initiative for the products included in this analysis.

Table 6. Lifespan Parameters* (years)

Generating Source	Uniform Range	Weibull Parameters	Uniform Mean	Weibull Mean
Desktop Computers				
Residential Consumer	3 - 12	Shape: 2.1, Scale: 7.6	7.5	6.7
Business/Public	2 - 7	Shape: 3.0, Scale: 8.4	4.5	7.5
Laptop Computers				
Residential Consumer	2 - 8	Shape: 1.7, Scale: 13.3	5.0	11.3
Business/Public	2 - 8	Shape: 2.9, Scale: 9.2	5.0	8.2
Mobile Phones				
Residential Consumer	3 - 7	Shape: 2.7, Scale: 4.2	5.0	3.7
Business/Public	3 - 7	Shape: 2.5, Scale: 4.0	5.0	3.5
Televisions				
CRT	5 - 20	Shape: 3.5, Scale: 9.5	12.5	8.5
Flat Panel	6 - 20	Shape: 3.5, Scale: 7.5	13.0	6.7
Projection	7 - 15		11.0	

*Temporary Diversion Primary and Secondary Use (includes storage)

Tables 7 through 9 present a comparison between EPA's 2015 model (uniform) and StEP Initiative (Weibull) distribution percentages which are applied to the historical sales data. For example, EPA's 2015 model assumes that 10 percent of the residential desktop computers (Table 7) sold 3 to 12 years previous are generated and ready for EOL management in the current year.

Table 7. Residential Computer Lifespan Distribution*

	Residential Desktop		Residential Laptop	
Age of Product	**Uniform**	**Weibull**	**Uniform**	**Weibull**
1		3%		2%
2		6%	14.3%	3%
3	10%	9%	14.3%	4%
4	10%	10%	14.3%	5%
5	10%	11%	14.3%	5%
6	10%	12%	14.3%	6%
7	10%	11%	14.3%	6%
8	10%	10%	14.3%	6%
9	10%	8%		6%
10	10%	6%		6%

Table 7. Residential Computer Lifespan Distribution*

	Residential Desktop		Residential Laptop	
Age of Product	Uniform	Weibull	Uniform	Weibull
11	10%	5%		5%
12	10%	3%		5%
13		2%		5%
14		1%		4%
15		1%		4%
16		1%		4%
17		<1%		3%
18		<1%		3%
19		<1%		3%
20		<1%		2%
21				2%
22				2%
23				2%
24				2%
25 to 30				7%

*percent of product ready for EOL management each year

Table 8. Residential Mobile Phone Lifespan Distribution*

Age of Product	Uniform	Weibull
1		5%
2		16%
3	20.0%	24%
4	20.0%	25%
5	20.0%	17%
6	20.0%	9%
7	20.0%	3%
8		1%
9		<1%

*percent of product ready for EOL management each year

Table 9. Television Lifespan Distribution*

Age of Product	Uniform CRT	Weibull CRT	Uniform Flat Panel	Weibull Flat Panel
1		<1%		<1%
2		1%		2%
3		2%		5%
4		4%		9%
5	6.3%	7%		13%
6	6.3%	10%	6.7%	17%
7	6.3%	12%	6.7%	18%
8	6.3%	14%	6.7%	16%
9	6.3%	14%	6.7%	11%
10	6.3%	13%	6.7%	6%
11	6.3%	10%	6.7%	3%
12	6.3%	7%	6.7%	2%
13	6.3%	4%	6.7%	<1%
14	6.3%	2%	6.7%	
15	6.3%	1%	6.7%	
16	6.3%	<1%	6.7%	
17	6.3%		6.7%	
18	6.3%		6.7%	
19	6.3%		6.7%	
20	6.3%		6.7%	

*percent of product ready for EOL management each year

The tabular data above are also presented in Figures 6 through 9. There is reasonable agreement between both models, aside from laptops. The StEP Initiative predicts a much longer, more spread out distribution of residential laptop lifespans based on analysis of survey data.

Figure 6: Comparison of Uniform and Weibull Distributions Residential Desktop Computer Lifespan

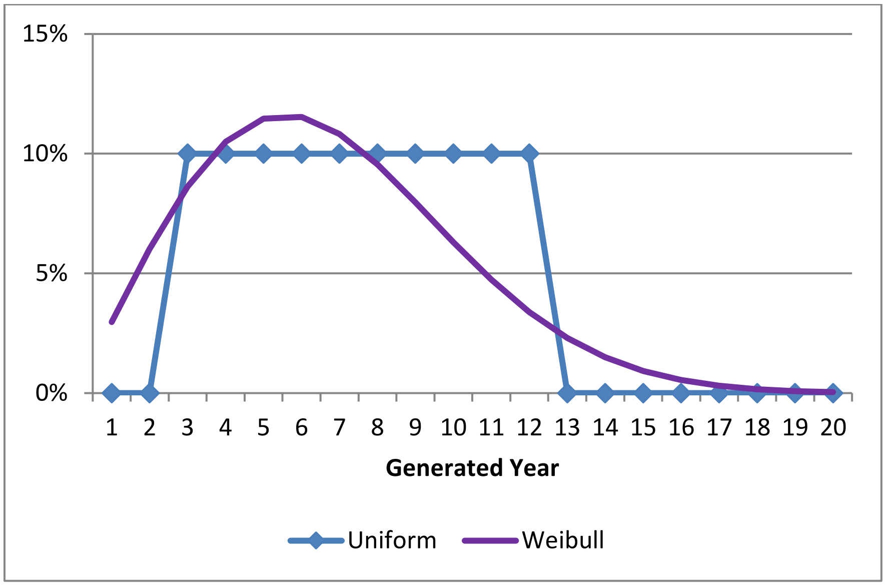


Figure 7: Comparison of Uniform and Weibull Distributions Residential Laptop Computer Lifespan

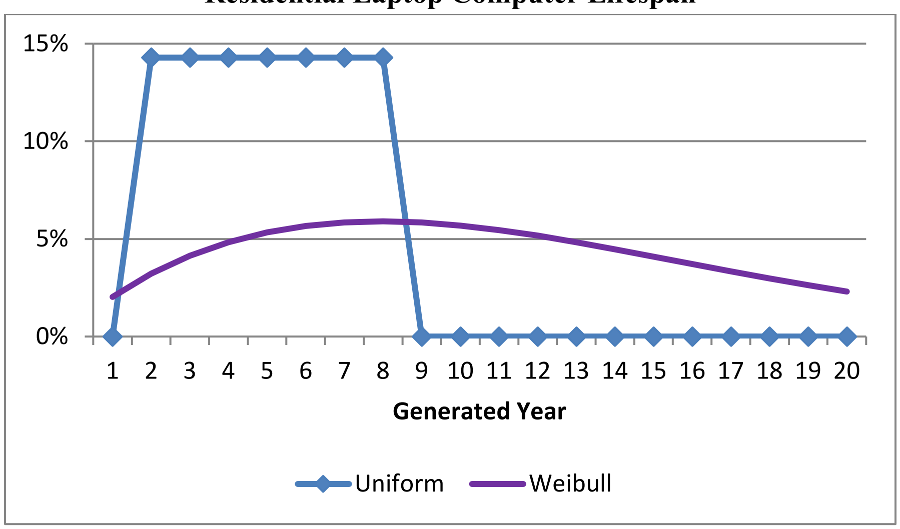


**Figure 8: Comparison of Uniform and Weibull Distributions
Mobile Phone Lifespan**

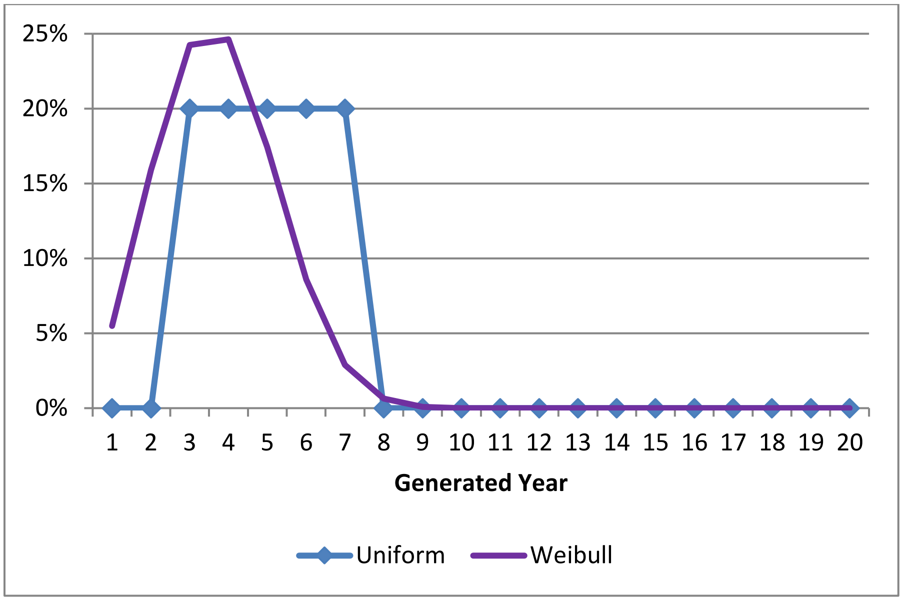
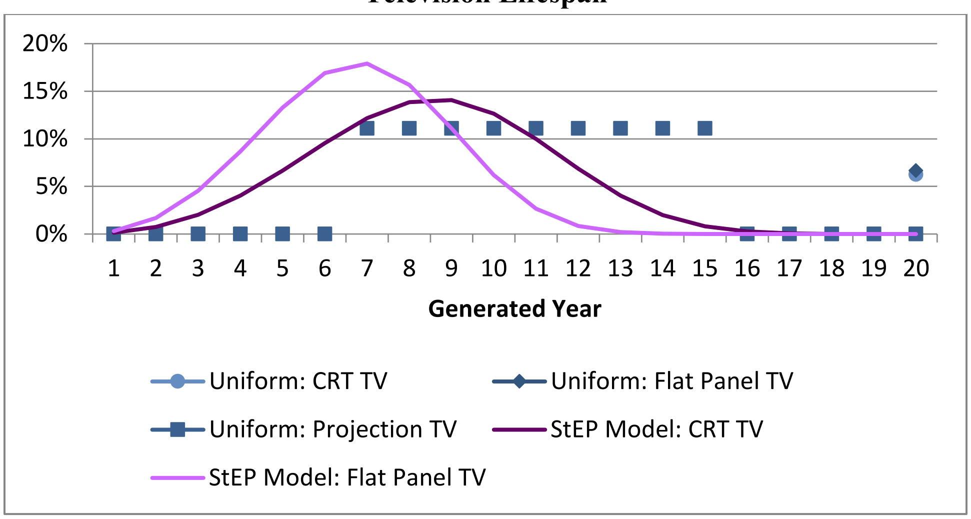


**Figure 9: Comparison of Uniform and Weibull Distributions
Television Lifespan**



2.4 Product Weight

There are two basic approaches for estimating the weight of generated used electronics: (i) estimate a representative weight of a new product when it was sold and carry that weight through the SOM model calculations, or (ii) characterize the weights of products that are generated in a given year at the point of collection. Ideally, both sets of data would be available for comparison and checking of the results.

EPA's 2015 model uses the first approach for all products except desktop computers which are based on approach 2. Data the Florida Department of Environmental Protection (DEP) gathered came from electronics collected for recycling from 2004 to 2006 and these data were used to calculate representative desktop computer weights prior to 2008 (as cited in EPA, 2011). For 2008 and 2009, manufacturer specification sheets were used to estimate the per unit weight for desktops. For 2010 through 2013, data captured by state take-back programs were used (NCER, 2014).

The StEP Initiative used weight data as presented in EPA's *Electronics Waste Management in the United States Through 2009* (EPA, 2011) for TVs and mobile phones. The weight data presented in that study also used a combination of the two approaches. The StEP Initiative used National Center for Electronics Recycling (NCER) data from Washington and Oregon in 2010 for desktop and laptop computers.

A challenge with the first approach is that this average needs to take into account the proportion of products of different weights sold in a given year to arrive at an average. In the case of a product like a laptop computer, there is only a small range of product weights to incorporate. Televisions, however, can range widely in size and weight. EPA's 2015 model incorporates television market share data when available.

Some states, like Florida Department of Environmental Protection, record the weight of collected products. If the records are sufficiently representative of recycled goods across the nation, then these datasets are helpful because the data are not reliant on the accuracy of representative weights. However, unlike the first method, it does not include electronics that are sent to combustion with energy recovery or landfilling; any difference in the average weight of electronics recycled versus combusted with energy recovery or landfilling is not accounted for. NCER maintains a Brand Data Management System of state recycling data for Extended Producer Responsibility purposes.

The product weights used by EPA's 2015 model and the StEP Initiative are included in the results section (Section 3).

3.0 Comparison Generation Results

The corresponding unit and weight results of EPA's 2015 model and the StEP Initiative are shown in Tables 10 through 13. Generation estimates of number of units and tons are fairly close for residential desktop computers, mobile phones, CRT TVs, and projection TVs.

Given the rapid increase in sales of laptops during their introductory phase, the two methods produce quite different laptop generation estimates; this would also be the case for other products with rapid initial sales such as flat panel monitors. Flat panel TVs also experienced a rapid growth in sales after 2005; affecting the generation results. Since the other products' sales did not have as steep an ascendancy in sales, the generation estimates are closer.

To illustrate the change rapid sales and differing lifespans have on generation estimates, EPA's 2015 model lifespan assumption for flat panel TVs was revised from six to 20 years to the StEP Initiative assumption of one to 15 years. The EPA 2015 model result would change to 17,754,000 units generated in 2013 (from 5,027,000 units) (see Table 13). This is due to large number of units sold in the past five years.

The product unit weights shown in these tables are very similar for both methods except for flat panel and projection TVs. EPA's 2015 model uses lower unit weights for both types of TVs. Generation of desktop, laptop, mobile phone, and TV units between 2000 and 2013 are shown in Appendix A.

Table 10. Desktop Computer Generation, 2013

Year	EPA Residential[1]	StEP Residential[2]	EPA Commercial[1]	StEP Commercial[2]
2013	**Generation (1,000 units)**			
	12,908	12,325	20,212	21,711
	Generation (1,000 tons)			
	143	144	231	254
weight (lb/unit)	22.14	23.40	22.88	23.40

1 Calculated using a uniform distribution
2 Calculated using a Weibull distribution

Table 11. Laptop Computer Generation, 2013

Year	EPA Residential[1,3]	StEP Residential[2]	EPA Commercial[1]	StEP Commercial[2]
2013	**Generation (1,000 units)**			
	19,508	7,954	14,865	11,265
	Generation (1,000 tons)			
	61	27	46	38
weight (lb/unit)	6.23	6.80	6.23	6.80

1 Calculated using a uniform distribution
2 Calculated using a Weibull distribution
3 If assume StEP lifespan of 1 to 30 years, the EPA result is residential 9,216 units.
This is due to few or no units sold prior to 1995

Table 12. Mobile Phone Generation, 2013

Year	EPA Residential[1]	StEP Residential[2]	EPA Commercial[1]	StEP Commercial[2]
2013	Generation (1,000 units)			
	126,764	133,745	50,366	46,278
	Generation (1,000 tons)			
	14	17	6	5.96
weight (lb/unit)	0.22	0.26	0.22	0.26

1 Calculated using a uniform distribution
2 Calculated using a Weibull distribution

Table 13. Television Generation, 2013

Year	EPA CRT [1]	StEP CRT [2]	EPA[1,3] Flat Panel	StEP[2] Flat Panel	EPA[1] Projection	StEP[2] Projection
2013	Generation (1,000 units)					
	21,666	18,807	5,027	20,920	2,395	2,385
	Generation (1,000 tons)					
	695	589.92	107	709.12	243	178.79
weight (lb/unit)	64.16	62.73	42.45	67.79	203.19	149.90

1 Calculated using a uniform distribution
2 Calculated using a Weibull distribution
3 If assume StEP lifespan of 1 to 15 years, the EPA result is 17,754 units. This is due to large number of units sold in the past 5 years

EPA's 2015 model generation estimates are similar to the StEP Initiative estimates when the products have a consistent sales pattern over time. In these cases, different lifespans and distribution methods do not result in large differences in the annual results. Consistent sales indicate a high market penetration of products. For example, in Table 13 CRT TVs, the difference between the two models is minimal (even though the models use different lifespans and different distribution models).

However, historical sales of flat panel TVs include a period of steep ascendancy after 2006. Inclusion or exclusion of any of these years in the lifespan assumption will greatly impact the resulting generation estimates. When EPA's 2015 model (2013 data) was revised to use the StEP Initiative lifespan assumption but maintained EPA's uniform distribution method, the results were similar (see Table 13 footnote 3). EPA model generation estimate for 2013 increased from 5.027 million units (Table 13) to 17.754 million units (similar to StEP 20.92 Table 13). Since the same historical sales data were used for both models, the difference between EPA's revised estimate of 17.754 million units and StEP's estimate of 20.92 million units is caused by the different distribution methods (uniform versus Weibull).

4.0 Comparison Recycling Methodology

Collected used electronics are those which are generated and destined for reuse (with or without refurbishing) or materials recycling as opposed to recycling with energy recovery or landfilling. When estimating the recycling of generated electronics, the three sets of data typically considered are: (i) combination of generation estimates with EOL habits as reported by residential and commercial consumers in the same sets of surveys used to determine lifespan; (ii) data from recycling programs; and (iii) surveys or reports from used electronics processors about the volumes of used electronics they recycled. When comparing these sets of data, an important criterion is how well each is able to characterize the entire flow of collected and recycled electronics.

There are many channels for recycling, and in order to get an accurate estimate, all must be included. Surveys have the benefit of being nationally representative and inclusive of all channels of collection and recycling, but are limited by the accuracy of survey responses.

Data from recycling programs, such as state mandated programs, often have the benefit of being tied to a system of payment for recycling and thus there is incentive for more precise accounting. However, the data are often aggregated across several product types, and solely using mandated recycling data excludes numerous other channels and will lead to an underestimate of recycling.

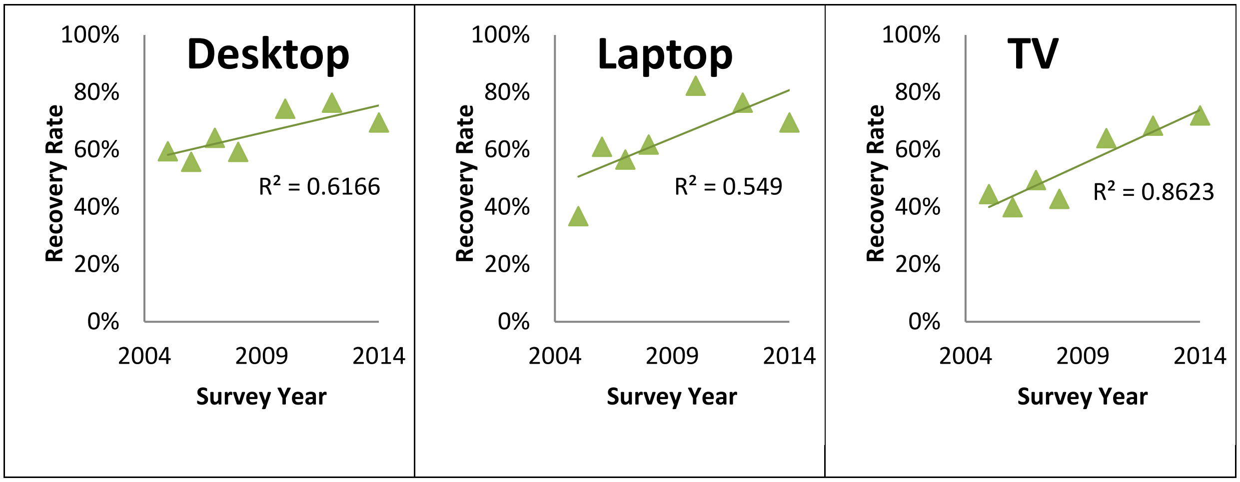
Data from used electronics processors are difficult to compile because the wide variety of size of companies in the industry and their varied reporting habits and willingness to participate in voluntary (or even mandatory) surveys. The U.S. International Trade Commission (USITC, 2013) conducted an extensive mandatory survey of the used electronics processing industry focusing on the year 2011 and was able to estimate over 757,000 tons of collected electronics were exported. As with the other model components, a comparison of data from the different approaches is ideal.

EPA's 2015 model relies on data collected at the state level. State websites and recycling reports were reviewed for electronic recycling data. In 2013, EPA identified tonnage data from 43 states representing about 87 percent of the U.S. population. There are four data gaps associated with this data: (i) most states only record data from municipal programs resulting in an undercounting of commercially generated products; (ii) the most current data available represent varying time periods; (iii) 13 percent of the population live in states with no reported data; and (iv) recycling is reported as total recycling with no individual product details.

To address these data gaps, EPA assumed the residential/commercial split of 33/67 used in EPA's 2011 electronics management report (EPA, 2011). EPA further assumed that electronics collection programs continue to exist at the same level as the most recent data available. For example, if a state reported data for 2012, the same tons were assumed for 2013 (i.e., no increase or decrease in tons recycled). Per capita factors were developed from the states with data applied to the population not represented by data. One factor was developed for states with aggressive regulations and a second factor was developed for those states with less or no regulatory requirements. Finally, EPA accepted total tons recycled and did not attempt to identify the composition by product or by material.

The StEP 2013 study (Duan, et al., 2013) utilized survey results conducted by different organizations of six different representative groups of U.S. residential computer owners from 2005 to 2012 (these figures have been updated with a 2014 survey). In doing so, the focus year of 2010 for the study was estimated in the context of somewhat steadily increasing recycling rates. The recycling rate is defined as the percentage of generated electronics that went towards recycling versus combustion with energy recovery or landfilling. Considering the different organizations and groups of respondents, the trends observed in Figure 10 are quite remarkable. The StEP Initiative applied the inferred recycling rates to their residential and commercial generation estimates.

Figure 10: Residential Recycling Rates Inferred from Seven Surveys from 2005 to 2014*



*Modified by the StEP Initiative to include 2014

5.0 Comparison Recycling Results

Applying the recycling methodologies discussed above to EPA's 2015 model and the StEP Initiative generation estimates results in the 2013 electronics recovery shown in Table 14. EPA's recycling can only be calculated as total recycling (and not for individual products). This assumes that only the products shown in Table 14 are included in the recycling estimates. Although these are the most common products recycled there is no way to estimate other types of products, for example gaming systems that are counted in the state data used to calculate EPA's recycling rate. Estimated generation of electronic products shown in Table 14 but not included in Section 2 of this document were estimated separately by EPA and the StEP Initiative authors.

The EPA recycling rate in Table 14 (62 percent) varies from the recycling rate shown in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013* report (40.4 percent) (EPA, 2015). This is because the group of products presented in Table 14 is for a subset of products included in the 2013 SMM report (EPA, 2015). However, the total tons shown as recycled in Table 14 (1,270,000 tons) are equal to the tons shown in the 2013 facts and figures report. In other words, the numerators are the same but the denominators are different. As stated above, this assumes that the products recycled only include the subset of products shown in Table 14.

Both methods estimate a high recycling rate. The StEP Initiative method estimates about 33 percent more tons recycled (1,698,000 tons compared to 1,270,000 tons).

Table 14. Consumer Electronic Product Recycling, 2013

Product	EPA	StEP	Recycling Percent of Generation
	1,000 tons	1,000 tons	
Desktop		287	72%
Laptop		51	78%
CRT Monitor		184	91%
Flat Panel Monitor		126	60%
Mobile Phone		15	65%
TVs		1,035	70%
Total Recycling [1]	1,270	1,698	
Percent of Generation	62%	70%	

1 The recycling rate shown in EPA's facts and figures report for 2013 is 40.4 percent (compared to 62% in Table 14) based on a broader set of consumer electronic products generated.

6.0 Recycled Electronics through Certified Organizations

Certification refers to the two certification programs launched in 2010 that provide electronics reuse and recycling organizations an accredited third-party auditing program to demonstrate that they meet certain standards for safely recycling and managing collected electronics. The two accredited certification standards are: (i) "Responsible Recycling Practices for Use in Accredited Certifications Programs" (R2: 2013 Responsible Recycling) and (ii) the e-Stewards standard. The R2 standard is managed by Sustainable Electronics Recycling International (SERI), and the e-Stewards Standard is managed by the Basel Action Network (BAN). According to EPA (EPA, 2014), both standards target:

- Reducing environmental and human health impacts from improper recycling;
- Increasing access to quality reusable and refurbished equipment to those who need them; and
- Reducing energy use and other environmental impacts associated with mining and processing of virgin materials and conserving our limited natural resources

As part of the National Strategy for Electronics Stewardship (Interagency Task Force, 2011), EPA and other agencies have promoted the use of facilities certified to either or both of the R2 and e-Stewards standards (i.e., certified recyclers). As the standards are relatively new, there has been no systematic attempt to measure the quantity of electronics that are received by these facilities. In order to develop the estimates, EPA looked at several sources of existing data, surveyed a small sample of key electronics recycling stakeholders, and compared their estimates for the percentage of electronic processed by certified recyclers to 2013 certified recycling estimates developed based on state data.

Some important caveats must be noted in examining certified recyclers and potential volumes managed at their facilities in 2013. First, this analysis did not make a distinction between the two standards; some recyclers were certified to one or the other standard, and some were certified to both. For the purposes of this analysis, a "certified recycler" was any organization that had obtained a certification to either the R2 or e-Stewards certifying body. Second, certification under these standards is facility-specific. Larger recyclers that have multiple facilities in several states might not have had all of their facilities certified to at least one of the certification standards. The standards have different policies regarding multi-facility organizations. The certified recycler processing estimates in this analysis assumed that a certified recycler with more than one location has certified all facilities. Finally, because this analysis examined calendar year 2013, the certifications under consideration were R2: 2008 and e-Stewards version 1.0. Both SERI and BAN announced updated versions of the standards in 2013 and phased out earlier versions of the standards in 2014 and 2015.

6.1 Methodology

EPA reviewed existing datasets and interviewed representative electronics recycling stakeholders to gather new data in order to estimate the quantity of collected products sent to certified electronics recyclers for processing in 2013. Used electronic recycling data have traditionally been limited. There have been few annual or regularly updated reporting mechanisms from which to gather data, and those that have attempted to collect data have run into challenges such as the lack of consistent data collection definitions and the potential for double reporting. For example, the local government agency that sponsors a collection program and the recycler that processes those collected products may report the same figures.

6.1.1 Existing Data

Beginning in 2004, states such as California and Maine passed statewide program legislation addressing the safe EOL management of used electronic products (ETBC, 2011). As of 2011, 25 states had passed and implemented some type of electronics recycling legislation. For the purposes of data collection, the laws created resulted in regularly updated reporting on total weight of used electronics collected and recycled in the respective state. Reporting in these states was mandatory, and in some cases, required identification of each recycler used to process the collected materials. For these reasons, this data gathering effort focused on the 25 states with used electronic product regulations in place.

As shown in Table 15 below, a total of roughly 366,000 tons (731 million lbs) was reported across 21 states[4] in calendar year 2013 or the most recent annual period (ERCC, 2014).

Table 15. State Program Collection Data 2013 (tons)

State	Total Reported Collected 2013 (or noted)
California [1]	101,748
Connecticut	6,615
Hawaii	2,070
Illinois	23,581
Indiana	10,229
Maine	4,092
Michigan	15,087
Minnesota [2]	16,150
North Carolina	17,882

[4] 4 of the 25 States did not have data available, or were unable to separate program data from data on other collections.

Table 15. State Program Collection Data 2013 (tons)

State	Total Reported Collected 2013 (or noted)
New Jersey	19,300
New York	49,750
Missouri	1,665
Oklahoma [3]	1,293
Oregon	13,864
Pennsylvania	21,758
Texas	10,386
Utah	3,800
Vermont [3]	2,439
Virginia [3]	2,059
Washington	22,590
Wisconsin [2]	19,378
Total	365,734

1 Tons claimed for payment to CalRecycle only, mostly CRTs
2 July 2012- June 2013
3 No TVs
Source: (ERCC, 2014)

There are several limitations to note when examining the state-reported data as the basis for estimating the quantity of collected electronic products processed by certified organizations. First, the reporting requirements varied from state to state in terms of which entity was required to report (manufacturer, recycler, etc.), which could have resulted in over- or under-reporting depending on who was required to report. Second, some state reporting laws only included devices collected from households, while others included items collected from small to large businesses and institutions. Finally, most states only required reporting of specific types of electronics covered under the legislation, leading to inconsistencies and undercounting in the quantities reported by different states. Table 16 summarizes the differences in products covered by each state law (ERCC, 2013).

Table 16. Scope of Products for U.S. State Electronics Recycling Laws[5]

State	Desktop Computer	Laptop	Monitor	TV	Printer
California		X	X	X	
Connecticut	X	X	X	X	X
Hawaii	X	X	X	X	X
Illinois	X	X	X	X	X
Indiana		X	X	X	
Maine		X	X	X	X
Maryland	X	X	X	X	
Michigan	X	X	X	X	X

[5] Limited to five most commonly covered devices. Other electronics covered under one or more of the 25 state laws include tablets, E-readers, fax machine, scanners, keyboards, mice, portable audio, portable DVD player, DVD player, VCR, small scale server, set-top boxes, game consoles and digital picture frames.

Table 16. Scope of Products for U.S. State Electronics Recycling Laws[5]

State	Desktop Computer	Laptop	Monitor	TV	Printer
Minnesota		X	X	X	
Missouri	X	X	X		
New Jersey	X	X	X	X	
New York	X	X	X	X	X
North Carolina	X	X	X	X	X
Oklahoma	X	X	X		
Oregon	X	X	X	X	
Pennsylvania	X	X	X	X	X
Rhode Island	X	X	X	X	
South Carolina	X	X	X	X	X
Texas	X	X	X	X	
Utah	X	X	X	X	X
Vermont	X	X	X	X	X
Virginia	X	X	X		
Washington	X	X	X	X	
West Virginia	X	X	X	X	
Wisconsin	X	X	X	X	X

Source: (ERCC, 2013).

Few states had data submission requirements for non-legislated electronic products collected and recycled (mandatory or voluntary). In some cases, such as Wisconsin, the total amount of non-covered (i.e., non-legislated) products collected for recycling exceeded the amount of covered products. Maine asks for voluntary submissions of data that are not reported through the local government collections funded by the law. These data show that in 2013, an additional 700 tons were collected through a voluntary manufacturer program. Adding this to the reported 4,050 tons reported through the program increased the annual pounds collected per person from 6.2 to 8.8 (Maine DEP, 2015).

California has two state agencies with used electronic reporting requirements. CalRecycle requires extensive reporting of products covered by the Covered Electronic Waste (CEW) Payment System law (mainly TVs, monitors and other video displays). The California Department of Toxic Substances Control (DTSC) requires "handlers" of Universal Waste to report quantities of non-covered electronics collected.

EPA requested data from DTSC on electronics reported by regulated handlers in 2013. Subtracting out quantities of CRT devices reported under the CEW Payment System (99 percent of CEW claims), there were approximately 85,000 tons of non-covered electronic devices processed in California in 2013. This is in addition to the 101,748 tons submitted to CalRecycle for payment (shown in Table 15) for a total 2013 recycling of 189,000 tons (9.69 lbs. per capita) (NCER, 2015).

State data provided a helpful breakdown of recycled electronic products sent to certified versus non-certified recyclers if the state reported amounts sent to individual recyclers. A list of recyclers was matched to the official lists of certified recyclers maintained by SERI and e-Stewards. NCER completed an analysis of the total tons reported in California, Connecticut, and Washington in 2013 (Table 17). The state-reported totals by recycler were matched against recycler certifications to develop the overall percentages. The three states were chosen to represent a mix of generating sectors. California included generation from all households and businesses, Connecticut covered household devices only, and Washington reported recycling from households and small organizations (NCER, 2015).

Table 17. Percentage of Tons Recycled/Claimed by Certified Recyclers in 2013

State	Total Reported (tons)	Percent Certified
California	100,675	78%
Connecticut	6,615	100%
Washington	22,590	83%

Source: (NCER, 2015)

Manufacturer programs were also beginning to report on the total volume sent to certified recyclers. The Consumer Electronics Association (CEA) reports member collection efforts through the eCycling Leadership Initiative. In 2013, eCycling Leadership Initiative participants reached 99.9 percent processed in certified recycling facilities (over 620 million pounds). The data reported by CEA had significant overlap with state-reported data. Therefore, CEA data could not be added to the state data reported above.

One final potential source of data is from the certification programs themselves. SERI (R2) has not announced plans to collect data from certified recyclers, but BAN requires e-Stewards to submit volume data.

Despite the availability of some electronics recycling data, there are a few key limitations that prevent the available data from providing the complete picture. Those limitations may also present challenges for estimating the percentage of electronics processed by certified recyclers in 2013. Limitations include:

- Electronics recycling data are only available from states with laws, so it is necessary to make assumptions for other states.
    - Half of the states have electronics recycling program laws, and the other half have very little, if any, mandatory reporting on quantities of electronics recycled. Assumptions are needed to estimate quantities of recycled electronics in the 25 states without laws.
- State data are limited to covered devices; few states report data on non-covered electronics.
    - In states where reporting is required under the program regulations, most do not require reporting for products outside the regulatory scope. In some cases, regulations only cover three or four major product types, which can leave a data gap for quantifying other recycled products.
- Little is known about collection and recycling from the commercial sector.
    - As with the product scope, state data are limited to the entities covered in the statutes. All state laws cover households, but only a few cover all types of businesses. Therefore, the available data on collected electronics tend to be dominated by devices collected from households. Even in states where some set of businesses and other entities (i.e. schools, government) are covered, household totals tend to dominate. For example, in Washington, one of the few states that report totals by entity, household weight represented 99 percent of the total compared to 1% for small business, small government and schools (WMMFA, 2014).
- Double counting of weight totals can occur when using a mix of data from state programs, recycler totals, and manufacturer programs.

- One of the largest challenges in using the state program data and other national data is ensuring that quantities are only reported once. Recycling of products tracked by national manufacturer programs overlaps with product recycling reported under state law reporting requirements.

6.1.2 Stakeholder Input

EPA contacted a limited number of representatives within the electronics recycling community for their perspectives on electronic product recycling through certified and non-certified organizations. The following questions were used to gain insight into the prevalence of certified electronics recyclers and the volumes processed:

- What percentage of e-scrap recycling firms are certified (R2 and/or e-Stewards)?
- What would you estimate is the volume (by percentage or total lbs/tons) of e-scrap going to certified (R2 and/or e-Stewards) firms vs. non-certified firms?
- Is there a difference between e-scrap coming from residential vs. commercial sources in terms of whether it ends up at certified vs. non-certified firms?
- Are some used products more likely than others to end up at certified vs. non-certified firms?

Survey respondents were chosen to be reflective of the industry overall, as well as certification programs. Because the existing state data were weighted heavily towards household/consumer recycling, a few representatives of the IT Asset Disposition (ITAD) side of the electronics recycling industry were chosen to be interviewed. ITAD companies were those organizations who focus on recovering high value IT devices from business users to refurbish and resell. Respondents fell into the following general categories.

- Industry Expert
- Auditing Consultant (all recyclers)
- Certification Programs
- ITAD: recycler and ITAD industry expert
- General recycler (small and large)

In addition, participants representing recyclers were asked the following questions to provide context on the type of services they offer and what markets they service:

- What recycling services do you offer? (Reuse with/without refurbishing, recycling, hand demanufacturing, shredding, etc.)
- What type of electronics do you collect (printers, computers, laptops, cell phones, TV's, gaming systems, etc.)?
- What percentage of each type of product do you reuse/refurbish? Is this in whole products or components?
- What percentage of each type of product do you recycle?
- What percentage of the electronics that you send for recycling goes to certified recyclers?
- What percentage of the electronics you reuse or recycled is collected from residential sources versus commercial source?

Each of the participants was asked to give their subjective estimate based on their knowledge of the current market. Some participants chose to not provide specific numbers with regards to their assumptions on the percentage of facilities or volume certified.

Table 18. Survey Responses on Questions Related to Certification

Question	Responses
% of Recycling Firms Certified	25%-80% (average 50-60%)
% Volume to Certified Firms	30-75% (average 50-60%)

With respect to the questions in Table 18 above, additional comments include:

- Since TVs are so heavy, the majority by weight are going to certified companies
- Without CRTs, the number would go way down
- Small percentage by volume are not certified– all big companies are certified to one or multiple standards
- Some scrap yards are getting large volumes of electronics but are not certified
- There is a sector of non-profits that also get large volumes but are not certified
- Almost all of the larger firms are now certified (large volume) and most of those not yet certified are the smaller ones (smaller volumes)

Participants were also asked if they observe a difference in the firms or volume recycled based on whether a recycler is active in the commercial or residential returns markets. Responses to this question were inconsistent, with some stating that the overwhelming majority of the household market is going to certified recyclers since it is dominated by CRT weight, while others observe that residential collectors aren't looking for certified recyclers in the same way that a commercial customer would. Still others felt that a large proportion of small and medium sized businesses still allow IT departments with little knowledge of certification to decide how to manage used electronics. Responses to this question included comments such as:

- More business to business companies are certified than consumer, those working with the commercial sector tend to be certified
- Large businesses have an interest in making sure their used electronics are handled properly and therefore use certified companies
- More are not certified in the non-legislative market; within legislative markets, most specify certified companies
- If an item has positive commodity value, it is less likely to go to a certified recycler because it will be siphoned off before reaching a certified recycler
- Commercial equipment often goes to waste hauling companies – difficult to specify that they can only use certified recyclers
- Electronics collected by original equipment manufacturers (OEMs) and state programs are going to certified recycling almost exclusively
- A higher percentage of all used electronics generated by businesses is recycled by certified companies because certification programs are promoting it. There is no similar program for consumer generated electronics. Residential consumers rely upon their (limited) knowledge of options and consequences and the availability of a conveniently located recycler or collection site that uses certified recyclers

Finally, participants were asked if the type of product being recycled plays a factor in whether it ends up at a certified recycler. Most agreed that difficult to recycle, low value products such as CRTs were likely going to certified recyclers. On the other side, some pointed out that cell phones may have a lower rate of recycling through certified recyclers since the companies that specialize in phone refurbishment and resale were not early adopters of certification. Comments for this question included:

- Value of a product makes a difference; more valuable products are not going to certified recyclers because of reuse markets; certification isn't a factor in that marketplace
- For products that can be refurbished, about 50 percent don't make it to a certified recycler
- At this stage, it would be very difficult to identify a trend related to products that get recycled by certified versus non-certified recyclers

Additional responses received from recyclers are shown in Appendix B.

Table 19. Percentage Comparison of Certified Recycling of Collected Devices from Existing Data and Survey

Source	% Certified 2013	Notes
State Data (CA, CT and WA)	78-100%	Can include business recycling, but mainly household collections
Survey Responses (volume estimate)	30-75%	Includes assumptions for business and household
CEA eCycling Leadership	99.9%	Mainly household collections

Using the overall estimate of the amount collected in 2013 of 1,270,000 tons or 2.54 billion lbs. (EPA, 2015), it is estimated that between 381,000 - 952,500 tons were sent to certified recyclers in 2013 (30 to 75 percent).

The analysis and interview responses show that there is a lack of data in certain areas of the electronics recycling industry, which leads to differing opinions on the amount currently being processed by certified recyclers. Within the more defined universe of the state law programs, existing data and interview data indicate that a large percentage (78 to 100 percent) is going to certified facilities. However, when the scope is widened to states without program laws, commercial recycling, and other products not covered by the state laws, the estimated percentage of material managed by certified recyclers and the volume managed vary widely. This is expected since actual collection and recycling activity data outside of state program laws is also scarce.

There are several issues to consider for future analyses that were brought up in the review of data and by industry participants.

- First, double- or even triple-counting is a serious concern for ensuring data accuracy. A local collector, a recycler, and a manufacturer program have the potential to count the same products separately as being part of their program.

- In addition, some recyclers may not fully process all materials types; therefore they sell whole products to other primary recyclers. If the pounds received at the first recycler are also counted by the second, it could lead to further double-counting of the same devices.

- A similar point was made by a few industry participants who asked "What is the definition of a recycler?" They noted that companies who engage primarily in collecting, refurbishing and brokering electronics, without engaging in demanufacturing, shredding, or other processing of electronics, could be certified. If those firms and the volume they receive are considered in the calculations, it also raises the possibility of counting the same products multiple times as it moves through the industry supply chain.

- The e-Steward program plans to have data on volumes recycled by their certified recyclers in the future. If a similar data collection program were instituted by SERI for R2 certified recyclers, it would help resolve many of the present data challenges. It should be noted that it is estimated[6] that one third of all certified recyclers are "dual-certified" to both R2 and e-Stewards. Therefore, an effort would need to be made to sort out totals reported by both certification programs to prevent double-counting in the future.

7.0 References

Methodology Comparison

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Appendix A
Electronic Products Ready for EOL Management Historical Generation Estimates

Appendix A Table 1. Desktop Computer Generation (1,000 units)

Year	EPA Residential Consumer [1]	StEP Residential Consumer [2]	EPA/StEP	EPA Business/ Public [1]	StEP Business/ Public [2]
2007	12,803	13,285	96%	22,362	20,234
2008	13,622	13,685	100%	22,131	21,074
2009	14,211	13,786	103%	22,290	21,628
2010	14,454	13,654	106%	22,342	21,940
2011	14,230	13,342	107%	21,736	22,043
2012	13,638	12,884	106%	21,053	21,963
2013	12,908	12,325	105%	20,212	21,711

[1] Calculated using a uniform distribution.

[2] Calculated using a Weibull distribution.

Appendix A Figure 1. Residential Desktop Generation 2007 to 2013 (1,000 units)

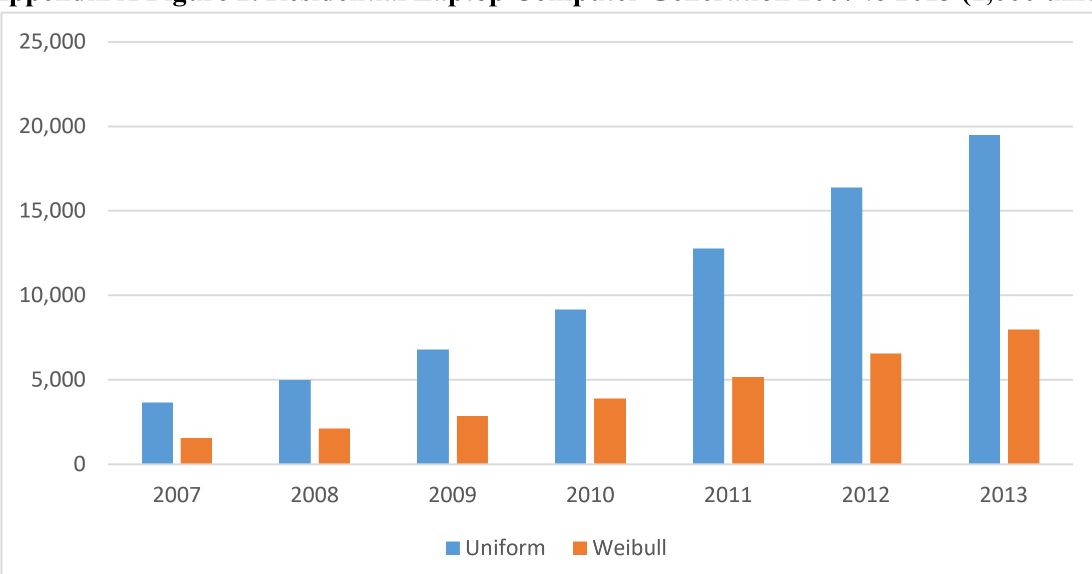
Appendix A Table 2. Laptop Computer Generation (1,000 units)

Year	EPA Residential Consumer [1]	StEP Residential Consumer [2]	EPA/StEP	EPA Business/ Public [1]	StEP Business/ Public [2]
2003	1,025	481	213%	5,666	3,391
2004	1,362	643	212%	6,215	4,074
2005	1,925	856	225%	6,702	4,741
2006	2,630	1,147	229%	7,226	5,389
2007	3,632	1,553	234%	8,055	6,033
2008	4,988	2,104	237%	9,025	6,709
2009	6,785	2,837	239%	10,205	7,454
2010	9,180	3,878	237%	11,402	8,287
2011	12,757	5,154	248%	12,508	9,213
2012	16,380	6,540	250%	13,754	10,219
2013	19,508	7,954	245%	14,865	11,265

[1] Calculated using a uniform distribution.

[2] Calculated using a Weibull distribution.

Appendix A Figure 2. Residential Laptop Computer Generation 2007 to 2013 (1,000 units)



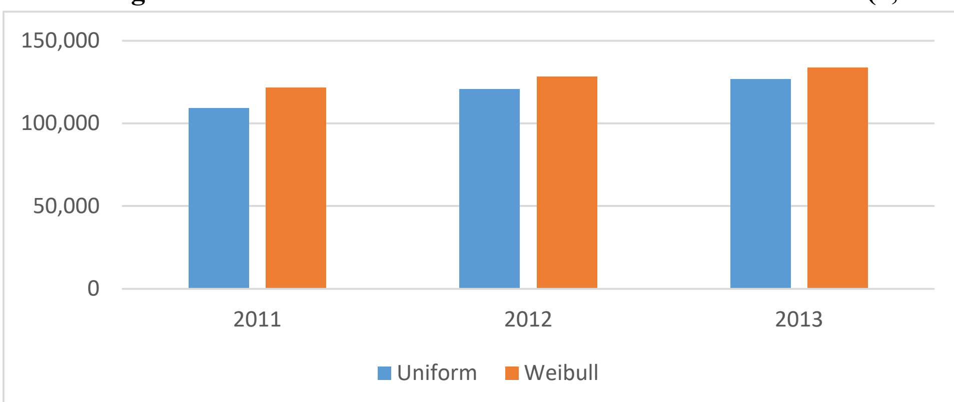
Appendix A Table 3. Mobile Phone Generation (1,000 units)

Year	EPA Residential Consumer [1]	StEP Residential Consumer [2]	EPA/StEP	EPA Business/ Public [1]	StEP Business/ Public [2]
2009	57,990	NA	NA	33,585	NA
2010	83,666	NA	NA	44,294	NA
2011	109,314	121,853	90%	53,730	49,801
2012	120,788	128,371	94%	49,706	49,012
2013	126,764	133,745	95%	50,366	46,278

[1] Calculated using a uniform distribution.

[2] Calculated using a Weibull distribution.

Appendix A Figure 3. Residential Mobile Phone Generation 2007 to 2013 (1,000 units)



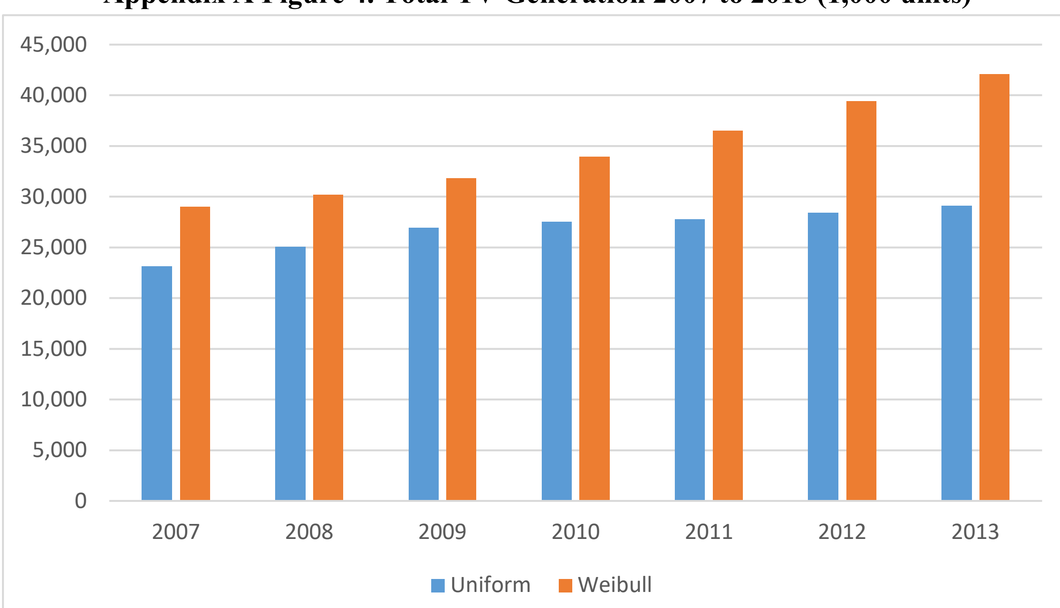
Appendix A Table 4. TV Generation (1,000 units)

Year	EPA CRT TVs [1]	StEP CRT TVs [2]	EPA Flat Panel TVs [1]	StEP Flat Panel TVs [2]	EPA Projection TVs [1]	StEP Projection TVs
2000	9,951	19,922	337	841	221	576
2001	11,528	21,565	385	865	281	695
2002	13,245	22,695	450	891	355	839
2003	15,022	23,502	523	921	464	1,007
2004	16,761	24,158	591	947	593	1,199
2005	18,306	24,738	657	993	712	1,414
2006	19,721	25,221	713	1,144	832	1,659
2007	21,404	25,531	770	1,530	975	1,935
2008	23,034	25,575	844	2,397	1,144	2,227
2009	24,592	25,260	943	4,048	1,385	2,495
2010	24,359	24,498	1,524	6,741	1,636	2,682
2011	23,975	23,207	1,829	10,579	1,963	2,736
2012	23,069	21,317	3,146	15,435	2,183	2,631
2013	21,666	18,807	5,027	20,920	2,395	2,385

[1] Calculated using a uniform distribution.

[2] Calculated using a Weibull distribution.

Appendix A Figure 4. Total TV Generation 2007 to 2013 (1,000 units)



Appendix B

Additional Recycler Responses

Recycler Question	Responses
What recycling services do you offer? (reuse with/without refurbishing, recycling, hand demanufacturing, shredding, etc.)	• everything • only shred hard drives, but everything else dismantled
What type of electronics do you collect (printers, computers, laptops, cell phones, TV's, gaming systems, etc.)?	• all • everything including all battery and cord
Can you provide an estimated volume of each type of electronics you collect in question 2?	• 8% computer, 12% monitor, 80% TV, 0.1% laptops • state program material 68% CRTs, 32% other other includes 89% CRTs, 1% laptop, 3% flat screen monitors, 7% flat screen TVs • 5% central processing units (CPUs)
What percentage of each type of product do you reuse/refurbish? Is this in whole products or components?	• 0.4% reused for state program material • from businesses, 40-60% resold
RECYCLER: What percentage of each type of product do you recycle?	• All, only wood from TVs is not recycled • If tracking to downstream, and what ultimately gets to raw material would be 87%
What percentage of the electronics that you send for recycling goes to certified recyclers?	• Almost zero – going to downstream that are audited, but not certified to R2/e-Stewards • Precious metal/battery/CRT glass downstream not certified • Only 25% by volume to certified downstream
What percentage of the electronics you reuse or recycled is collected from residential sources versus commercial sources?	• 80 consumer, 20 commercial • 50/50 • 95% commercial/5% household

Appendix C

Mobile Phone Reuse, Refurbishment, and Materials Recycling

Currently the EPA Advancing Sustainable Materials Management report series does not provide detail on individual consumer electronic product recycling rates. The focus of this initial research is scoping out the possibility of determining a recycling rate for mobile phones. Given that in 2013 there were 96 active mobile phones lines for every 100 people in the U.S. (The World Bank, 2014) and each mobile phone is replaced every two years on average (Entner, 2014), environmentally responsible collection for reuse, refurbishing, and materials recycling of mobile phones is a solid waste management concern. EPA developed a list of questions for representatives of the mobile phone recycling industry to gain insight into mobile phone reuse, refurbishment, and materials recycling in the U.S.

EPA used the following methods to carry out the interview of businesses involved in mobile phone collection, repair, refurbishment, resale, and materials recycling. Eight companies were identified as potential participants, including two mobile device collector/ recyclers, one large and one medium-sized recycler, three remanufacturers, and one broker. EPA first contacted each company by e-mail to inform them of the survey. EPA then called each company to request their participation and administer the list of questions if the company agreed to participate. Each company was asked to provide the annual weight and/or number of mobile phones processed in 2013, a percentage breakdown of how mobile phones were managed, their source (residential or commercial), and whether or not phones destined for recycling are sent to a certified recycler. The questions are listed below.

- What recycling services do you offer (collection only, reuse with/without refurbishing, recycling, hand demanufacturing, shredding, etc.)?
- Can you provide an estimate of the annual weight and/or number of phones that you collect or receive for reuse or recycling? Does the weight of the mobile phones processed include the weight of batteries, chargers, or any other accessories?
- If you only provide collection services, where do you send the collected phones?
- What percentage of phones you receive are sold for reuse? (If possible, specify percentages for direct to reuse and repair to reuse.) What percentage are whole products versus components/parts?
- What percentage of phones do you refurbish?
- What percentage of phones do you recycle?
- Where do you send phones for recycling? What percentage of the recycled phones do you send to certified recyclers?
- What is the remaining percentage or annual weight of material that goes to disposal? Is this waste sent to a landfill or waste-to-energy incineration facility?
- What percentage of the phones you reuse, refurbish, or recycle is collected from residential sources versus commercial sources?

Five of the eight businesses contacted by EPA expressed interest in participating. Three companies completed the entire survey and two companies answered six of nine questions. The companies that responded to the survey processed more than 2.1 million mobile devices, or about 284 tons, in 2013. Table C.1 presents the results for average reuse, recycling, and disposal rates, weighted based on the weight of phones handled by each company. Reuse rates include both reused and refurbished phones since data were not sufficient to calculate separate rates. Three of the participating businesses have R2 and ISO 14001 certifications, and since any mobile phone material that cannot be reused is recycled, they did not report any disposal in landfills or by incineration. However, one participant noted that circuit boards, which make up a large fraction of a recycled phone by weight, are generally sent to smelting facilities to recover precious metals. During the process of isolating the precious metals for reuse, the remaining substances are likely incinerated. Thus, further research is needed to determine the actual percentage of materials collected for reuse from recycled mobile devices.

Appendix C Table 1. Reuse and Recycling Rate Results from Five Mobile Phone Recycling Organizations

	2013
Average reuse[1] rate	58%
Average recycling rate	42%
Average disposal rate	0%

1. Reuse includes refurbished mobile phones.

Appendix C Table 2. Organizations Contacted for Mobile Phone Recycling Survey

Business Name	Business Type	Level of Participation
ecoATM, Inc.	Collector	full participation
Call2Recycle, Inc.	Collector	full participation
HOBI International, Inc.	Recycler	full participation
Belmont Trading Company	Recycler	did not participate
Brightstar Corporation	Remanufacturer	did not participate
Valutech Outsourcing, LLC	Remanufacturer	partial participation
Teleplan International N.V.	Remanufacturer	partial participation
Reagan Wireless Corporation	Broker and Remanufacturer	did not participate

The limited nature of this survey resulted in the documentation of only a piece of the mobile phone reuse, refurbishment, and materials recycling industry. The mobile phones recycled by the participants (2.1 million) are 1.19 percent of the 2013 estimated mobile phones ready for EOL management (Table 12 in Section 3 of this document). Without a central data collection point for these types of data, it is difficult to estimate a recycling rate for all mobile phones.

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