Light at the End of the Tunnel for Electronics Energy Use?

Mateusz Malinowski, John Clinger, and Rachel Unger, ICF International
Bruce Nordman, Lawrence Berkeley National Laboratory
Katharine Kaplan, Environmental Protection Agency

ABSTRACT

Past estimates of energy consumption have cautioned about the increasing impact of miscellaneous loads and electronics; however, concerted effort has led to significant progress. Nine new and revised ENERGY STAR® electronics specifications have been finalized since 2012, and as manufacturers strive to meet the specifications, substantial U.S. energy savings are expected before 2020.

Despite growing interest in electronics, their total impact has not previously been known. This paper presents the first estimate of energy consumption for all electronic devices: 385 TWh/year ($41 billion/year) for 2010, or 14% of buildings electricity use. Notably, less than 10% of electronics energy use occurs in data centers. ENERGY STAR now covers products responsible for over 96% of this energy consumption, showing that policy has significant grasp of the end use. A further analysis of two scenarios based on ENERGY STAR data shows likely decreases in future energy consumption: replacing installed electronic devices with ones currently shipping would result in a total energy consumption of 206 TWh/year, while replacing them with products meeting ENERGY STAR levels could decrease this further to 154 TWh/year.

Introduction

In the past four decades, substantial increases have been made in the efficiency of traditional energy end uses in buildings. Efforts to tackle miscellaneous and electronic devices were much slower to start, and the number and usage of these devices has grown significantly over that time. Due to these factors, reasonable concern has been raised about how much they will contribute to future building electricity use, with "other" consumption (including appliances and lighting) accounting for 60% of electricity in new low-energy homes (Brown et al., 2006).

Since 1992, the ENERGY STAR program has covered an increasing portion of the electronics end use[1], and the electronics industry has focused more on the energy use of products. Technologies developed initially for mobile devices have often found their way into mains-powered devices. With all this change, it is time to reconsider the total impact of electronics energy consumption.

In the past 15 years, many studies have been done that estimate the energy use of subsets of the electronics end use (usually by considering only one building type or group of product types), but apparently none that have estimated the total for the U.S. This paper fills that gap. We have produced two estimates: one based on public data, and the other on data from the ENERGY STAR program.

[1] ENERGY STAR also covers a few product types in the miscellaneous end use but they are not covered in this paper.

Tracking the energy use of electronic products is challenging. The number of product types is large, often with significant variation in functionality and energy use within each one. The technologies they include can change substantially over the course of just a few years. Usage patterns are much more diverse than with other end uses, and often difficult to ascertain (Banerjee, et al. 2007). This paper presents a summary of existing sources in the literature of electronics energy use as well as data developed internally to the ENERGY STAR program, for purposes of assessing energy savings.

Energy Use Estimate Based on Publicly Available Data

This estimate collects data from existing sources to calculate the total amount of electricity consumed by electronic devices in the U.S. Electronics are "any device whose primary function is information" (Nordman and Sanchez 2006). This end use is predominantly made up of devices traditionally called Consumer Electronics and Information Technology. The estimate:

- Gives an overall quantitative picture of the electronics energy end use.
- Does not include equipment often associated with electronics such as uninterruptible power supplies and cooling systems (as in data centers).
- Is not aligned to a single year. Most data are for 2010 and the remaining for 2008, which is close enough for this purpose.

Data Sources

Residential data are from Urban, Tiefenbeck, and Roth (2011; data for 2010) except for network equipment and printers, copiers, MFDs, and scanners; these are from EPA (2011; data for 2010)[2]. Commercial data are from McKenney et al. (2010; data for 2008) except for imaging equipment, which are from EPA (2011; data for 2010)[3,4]. McKenney et al. combine desktop and notebook PCs. Servers, storage, and the data center part of network equipment are from Koomey (2011) and are the average of the "upper bound" and "lower bound" estimates for 2010. Network equipment data are from Lanzisera, Nordman, and Brown (2012; data for 2010).[5] The network (communications) value for data centers is from Koomey (2011), with the remainder (subtracting residential and data center from the total) allocated to commercial. Telecom network equipment[6] is listed in commercial to keep distinct from server-oriented data centers. U.S. electricity consumption figures by sector are from EIA (2013; data for 2010).

[2] Many estimates are not disaggregated by building type, so that all A/V energy is assigned to residential even though some of this occurs in commercial buildings.
[3] Not included, but arguably electronics: ATM, Arcade, Slot Machine, Landscape Irrigation (all from McKenney).
[4] A 2008 estimate on commercial Voice-over-Internet Protocol (VOIP) phones found an average power of 3.6 W. We assume that there are 50 million of these phones based on recent U.S. shipments of 7 million and a 7 year lifetime, and each uses 3.6 W (this may be low as some VOIP phones use over 10 W), which results in 1.6 TWh.
[5] The total is 20.5 TWh, and residential devices are 7.1 TWh.
[6] Does not include base stations.

Results

The primary results of our compilation are presented as the "Public" column of Table 2; all data in this section are for that estimate. The 385 TWh/year for all electronics is 14% of all buildings' (residential and commercial) electricity use (2,776 TWh).[7] In addition, we summed the data by building type, and found the percentage and absolute amount to be modestly higher in residential buildings (14%) compared to commercial (12%). Below we review select additional results while the next section of the paper presents a similar analysis for products covered by ENERGY STAR.

Data centers. Energy use in data centers receives substantial attention. Therefore, we sought to identify the portion of electronics energy use that occurs in data centers. This estimate covers only electronic devices in data centers, not equipment for cooling or reliable power delivery; these collectively can use as much as the electronics in some facilities. Many servers are outside of data centers—in ordinary offices, telecom closets in office buildings, or in rooms with multiple servers and dedicated cooling. There is no clear delineation of how many servers need to be in a space for it to be considered a "real" data center, nor good data on the distribution among these various space types. In preparing the Report to Congress in 2007 (Brown et al. 2007), IDC data indicated that half of servers were in spaces other than traditional data centers; other sources assume all servers are in data centers. In the absence of better data, we assume that 25% of servers (but no data center storage) is in commercial buildings, not data centers; this reduces the data center total by 7.3 TWh/year. As a result, data center electronics represent 9% of the energy use of all electronics.

Internet protocol connectivity. An increasing portion of electronics energy use is from devices that use the Internet Protocol (IP) in communications[8]. Some product types always have IP connectivity, such as computers and network equipment. For some product types, only a portion of devices offer IP connectivity (e.g., printers, some of which use only USB). Other product types never do (e.g., VCRs). Still other categories traditionally do not, but are gaining IP connectivity, most notably televisions. While not listed in this paper, we identified what portion of each product type has IP connectivity, and whether it is a "traditional" or "emerging" IP product type; the percentages are judgments by the authors. The great majority of this energy use is in device types that traditionally are mostly or entirely IP-connected, making this a relatively reliable figure.

From these data and our estimates, IP-connected electronics encompass 67% of all electronics energy use, and 85% of this is in product types that traditionally have IP connectivity.

ENERGY STAR coverage. The ENERGY STAR program has prioritized the types of products to cover based primarily on their collective energy use. Ninety-six percent of electronics energy use is addressed by existing ENERGY STAR specifications or ones actively under development. For any specification, there are typically exclusions for devices that are particularly large or small, or have other niche characteristics. So, coverage is best seen as "program coverage" in a

[7] While data centers are usually considered to be industrial facilities, for this comparison we include the energy use of electronic devices within them in the electronics total.
[8] IP connected devices in other end uses (HVAC, lighting, appliances, and miscellaneous) are not included.

general sense; evaluation of each product type would be required to determine actual coverage of products eligible to attain the label.

Energy Use Scenario Based on Current ENERGY STAR Data

The ENERGY STAR program recognizes and markets top-performing products and realizes energy savings as manufacturers strive to meet the requirement—a process illustrated in Figure 1. The ENERGY STAR requirement level is typically set such that it can be met by the best-performing quartile (25%) of products in each sub-category covered by the specification, based on model counts in a representative dataset.

The ENERGY STAR program covers over 70 product categories including 29 electronic product types in 10 specifications. The oldest specifications, for computers and displays, were first published in 1992 (since revised multiple times), while the newest as of May 2014, for small network equipment, took effect in September 2013 (EPA 2012a). Of the 10 electronics product specifications, eight have recently been subject to energy savings analyses due to new or revised specifications. The results of these analyses, as well as of several others for products not currently covered by a specification, are the subject of this section.

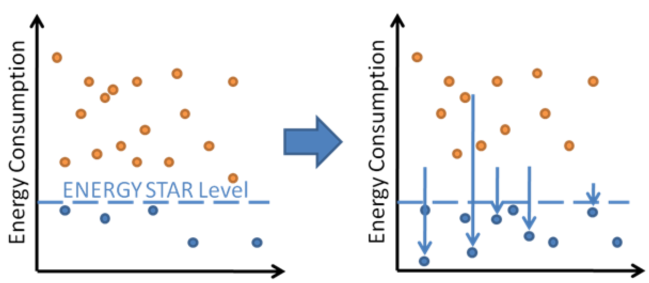

Figure 1. General illustration of energy consumption of Models in the market decreasing to meet the ENERGY STAR specification resulting in energy savings.

ENERGY STAR Savings Analyses

The ENERGY STAR Product Development Team estimates energy savings when evaluating new or revised requirements. These analyses quantify the expected energy, monetary, and carbon dioxide savings from the proposed specification levels. They are conducted when first evaluating the product for inclusion in the ENERGY STAR program, subsequently when developing Draft 1 of the specification, and again when developing the Final Specification.

The purpose of these analyses is to produce savings information (or the difference between one efficiency level and another) for use in evaluating requirement levels, but absolute values of energy consumption are also calculated as intermediate outputs. These specifications cover products that account for the vast majority of electronics energy consumption, and, the analyses were conducted recently. Thus, the results provide an updated insight into the possible future of electronics energy consumption.

Methodology

Although the electronic products covered by the ENERGY STAR program vary widely, the energy savings analyses follow a standard methodology, which differs from that used to calculate the total energy consumption using public sources. In particular, unit energy consumption is that of products currently sold, not that of the installed base, while the stock of products is typically calculated by multiplying recent sales by the lifetime, so it may likewise vary compared to the installed base. The methodology is described in more detail below, with product-specific details summarized in Table 1.

Table 1. Product-specific details of the ENERGY STAR analyses

Product type	Analysis type	UEC of non-ENERGY STAR product (kWh/year)	Definition of non-ENERGY STAR level	UEC of ENERGY STAR product (kWh/year)	Definition of ENERGY STAR level	Daily usage profile	Ship-ments or stock year	Life-time (year)
Audio equipment	Final spec	41	(Urban, Tiefenbeck and Roth. 2011)	18	Avg. meeting V3.0	(Urban, Tiefenbeck and Roth. 2011)	2012	7
Blu-ray	Final spec	16	Avg. meeting V2.0	15	Avg. V3.0 levels	0.7 h active 2.5 h idle 20.8 h sleep	2012	7
Game consoles*	Final spec	262	Avg. 7th- Gen Models	46	Avg. V1.0 levels	1 h active 7.6 h idle 15.4 h sleep	2012	N/A
Projectors	Scoping	168	0.08 W/lumen ultra-high perf. lamp	146	0.07 W/lumen ultra-high perf. lamp	3.3 active 10 partial on 10.7 off	2012	6
Cordless phones	Final spec	11	Avg. not meeting V3.0	7	Avg. V3.0 levels	24 h partial on	2014	7
VOIP phones	Final spec	35	Avg. not meeting V3.0	21	Avg. V3.0 levels	24 h partial on	2014	7
Femtocells	Scoping	70	Typ. current UEC	56	20% potential reduction	24 h active	2011	N/A
Desktops	Final spec	286	Avg. meeting V5.2 and avg. V5.2 levels	176	Avg. V6.0 levels	8.4 h short idle 3.6 h long idle 1.2 h sleep 10.8 h off	2014	4
Notebooks	Final spec	66	Avg. meeting V5.2 and Avg. V5.2 levels	45	Avg. V6.0 levels	7.2 h short idle 2.4 long idle 8.4 h sleep 6 h off	2014	2.5
Monitors	Final spec	98	Avg. meeting V5.1	32.94	Avg. V6.0 levels	4 h on 6 h sleep 14 h off	2012	4.5
Medical imaging	Scoping	119,728	Avg. of current models	79,819	30% savings	24 h on	N/A	N/A
Personal data storage	Scoping	13	Avg. bot. 75% of hard drives	4	Avg. top 25% of hard drives	1 h on	2008	5
Interactive whiteboards	Scoping	518	350 W typ. display	369	28% savings in on mode	4 h on 20 h standby	2013	6

Product type	Analysis type	UEC of non-ENERGY STAR product (kWh/year)	Definition of non-ENERGY STAR level	UEC of ENERGY STAR product (kWh/year)	Definition of ENERGY STAR level	Daily usage profile	Ship-ments or stock year	Life-time (year)
Small network equipment	Final spec	37	Avg. not meeting V1.0	30	Avg. V1.0 levels	24 h on	2013	4
Large network equipment	Scoping	1422	Per-port industry avg.	651	Per-port consumption of a more efficient router	8 h 100% load 8 h 70% load 8 h idle	2007	10
Imaging commercial	Final spec	441	Avg. meeting V1.2 and Avg. V1.2 levels	174	Avg. meeting V2.0	For TEC: profile from V2.0 and for OM: 12 h sleep 12 h standby	2014	5
Imaging residential	Final spec	17	Avg. meeting V1.2 and V1.2 levels	8	Avg. meeting V2.0	12 h sleep 12 h standby	2014	5
Set-top boxes (MVPD**)	Final spec	113	Avg. meeting V3.0	74	Avg. meeting V4.1	7 h on 10 h sleep 7 h auto-sleep, otherwise on	2014	7
Set-top boxes (non-MVPD**)	Final spec	51	Avg. meeting V3.0	20	Avg. meeting V4.1	7 h on 10 h sleep 7 h auto-sleep, otherwise on	2014	7
Televisions	Final spec	130	Avg. meeting V5.3	89	Avg. meeting V6.0	5 h on 19 h sleep	2013	6

* Instead of a traditional ENERGY STAR specification, there is an EPA manufacturer recognition program for Game Consoles. However, the specification development process was similar, so the data are included here.
** Multi-channel video provider. Non-MVPD set-top boxes are also known as over-the-top or streaming boxes.

Unit energy consumption (UEC). Models currently offered for sale are divided into groups based on their ability to meet a current, proposed, or potential ENERGY STAR requirement[9]. Average energy consumption for each group is then calculated based on the measured power of units in the group or the relevant ENERGY STAR requirement level. Finally, the UEC for the product type as a whole is estimated by multiplying the average energy consumption for each group by its corresponding proportion of the market and summing the results. As most product categories are composed of multiple subtypes (e.g., televisions of various sizes), the above analysis is conducted for each subtype. The resulting UEC for each subtype is multiplied by its corresponding proportion of the market and the results are summed once more, to obtain a shipment-weighted average UEC for the product as a whole.

National energy consumption (NEC). To calculate the NEC, the UEC is multiplied by the stock of products, where a suitable estimate is available. Otherwise, the stock is calculated by multiplying the most recently available shipments estimates by the average lifetime.

[9] Many of the ENERGY STAR requirements have since been finalized, but were considered “proposed” or “potential” at the time of the analyses. Similarly, then-current ENERGY STAR requirements are now former requirements.

Data Sources

The above calculations are based on the following measurements and data as well as assumptions about power and energy consumption, usage profiles, equipment stock, lifetimes, and shipments.

Unit power and performance. The primary source of product energy consumption is measured power data in each mode from independent laboratories reported to EPA and published online as Qualified Product Lists (QPLs). When there is no QPL (e.g., a new product category or scoping analysis) or QPL data are not representative of the entire market (e.g., only 30% of products shipped the previous year were ENERGY STAR certified), the dataset is supplemented with data from other sources: manufacturer submissions or reviews of products available for sale in manufacturer catalogs or websites.

Usage profiles. Power data must be multiplied by a usage profile or duty cycle to obtain an annual UEC. Usage assumptions are sometimes included in the ENERGY STAR test procedure or specification (and the resultant requirement levels expressed in kWh per week or year); in these cases the same assumptions are used in the analysis. For less-frequently used products or products that operate primarily in one mode, the requirement levels are expressed as power in each mode (in watts). In these cases, usage assumptions must be taken from elsewhere, such as other standards, studies, or usage of related products (e.g., set-top box usage is related to television usage). In a few cases, a usage profile was developed based on the authors' judgment. For example, consumer imaging equipment is assumed to be used so infrequently that the annual energy consumption is composed of a 50% weighting of both sleep mode and a standby power level[10]. All usage assumptions are documented in Table 1.

UEC. As mentioned above, the data are averaged based on product subtype and efficiency group (ENERGY STAR and non-ENERGY STAR[11]), to obtain an average UEC for each significant portion of the market. In most cases, the UEC for each model was used to develop the average; however, in some cases the applicable ENERGY STAR requirement level is used as a proxy for the model power or energy consumption.

When the QPL is supplemented with additional model data (as mentioned above) and the UEC of these additional models is not available (e.g., for models found through catalogs or websites), it is assumed to be equal to the ENERGY STAR specification level then in effect. The logic is that if their energy consumption were any less, the models could meet the specification level and would have appeared in the ENERGY STAR dataset.

This situation is illustrated in Figure 2. Using the current ENERGY STAR level as a proxy of the energy consumption of models not on the QPL will understate the energy consumption of this group and the total market. On the other hand, using the proposed ENERGY STAR level as a proxy of the energy consumption of models that can meet it will overstate of the ENERGY STAR group.

[10] For imaging equipment, standby is defined as the lowest power mode and can be off, sleep, or ready mode.
[11] This applies to the analyses conducted as the ENERGY STAR requirements were being finalized. For products being scoped for inclusion in the ENERGY STAR program, a potential future ENERGY STAR level was used as the cutoff.

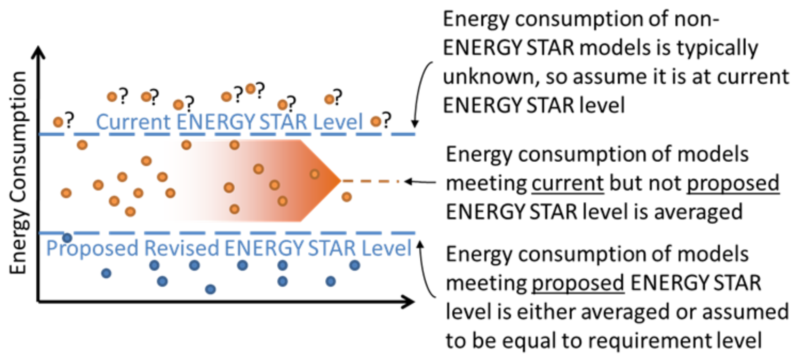

Figure 2. Illustration of how the energy consumption of the various groups of models in the dataset is either averaged or assumed to be equal to a particular requirement level.

Market share. Energy consumption across product subtypes and efficiency groups is then averaged to calculate a weighted average UEC for the product. This weighting is based on shipments, or when fine-grained shipment data are not available, on model counts. EPA's ENERGY STAR Unit Shipment and Market Penetration Reports (EPA 2012b) are a principal source of data on shipments and the proportion of models that can meet the ENERGY STAR requirements. This report is based on a survey of ENERGY STAR Manufacturing Partners and other market information, and indicates how representative the QPL is of the entire market.

Shipments and lifetimes. Total market shipment data are typically based on Consumer Electronics Association estimates (CEA 2012; CEA 2013). Lifetimes are from public sources, or derived from those for similar products. The stock is calculated by multiplying the shipments in the most recent year available by the lifetime.

Results

The results of the ENERGY STAR analyses are shown in Table 2, which includes subtotals per category and grand totals. The ENERGY STAR analyses cover 70% of the electronics end use calculated from the publicly available estimates. For both the ENERGY STAR and publicly sourced estimates, when a product type is missing in one, data from the other analysis is used in calculating grand totals to permit comparison between the estimates. The resulting total electronics estimate is 206 TWh/yr.

Energy Use Scenario Based on 100% ENERGY STAR

ENERGY STAR specifications save energy by incentivizing the sale of the best-performing product models. Since qualified products are clearly attainable, it is reasonable to consider a scenario in which all products sold are ENERGY STAR qualified, as illustrated in Figure 3. In reality, it would require many years, to remove all old products from use, so this is not a forecast of consumption in any future year. Rather, it shows what is possible with currently available technology.

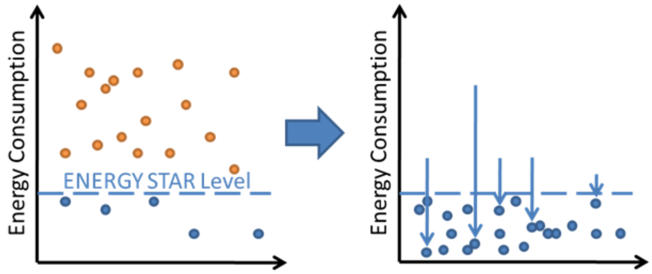

Figure 3. Illustration of energy savings as 100% of products are redesigned to meet the ENERGY STAR specification.

Results

The average UEC and NEC with the entire market at ENERGY STAR levels are shown in Table 2. The assumptions are the same as for the analysis of current energy consumption based on ENERGY STAR data, with the exception that rather than the current distribution of efficiencies in the market, an assumption of 100% ENERGY STAR is used. Under this scenario, and supplemented with public-source data for categories for categories where no ENERGY STAR analyses were conducted, the total energy consumption for all U.S. electronics is 154 TWh/year.

Overall Results

The results of the three analyses are shown in Table 2, displaying a trend of decreasing energy consumption for most categories. The publicly available analysis is based on data from 2010 and earlier, the ENERGY STAR analysis, mostly on data from 2012 and 2013, sometimes extrapolated to 2014.
The estimate and the two scenarios also differ in some other important respects. The ENERGY STAR analyses base stock levels on recent shipments and product lifetime, which may not always match that currently in use in buildings. Also, the UEC levels for non-ENERGY STAR models are generally from current-year products so that higher levels of legacy products still in operation will not be reflected in the total. For these reasons, we should expect there to be a significant difference between the estimates, and the results show that. Key results are:

- All electronic devices in the U.S. use approximately 400 TWh/year, with significant potential for reductions as more efficient products replace less efficient products
- About 10% of that occurs in data centers.
- Two-thirds of electronics energy use is by devices with IP connectivity[12].
- Residential electronics energy use is slightly higher in absolute and relative terms than in commercial buildings (196 TWh and 14% compared to 155 TWh and 12%, respectively for the public estimate)

[12] Some product types are always capable of Internet connectivity; some never are; and for the rest we determined a percentage of the stock that has the capability.

Table 2. Combined results of the three analyses

Product category	Public sources estimate (2008–2010) UEC (kWh/yr)	Public sources estimate (2008–2010) U.S. NEC (TWh/yr)	Current ENERGY STAR scenario (mostly 2012–2014) UEC (kWh/yr)	Current ENERGY STAR scenario (mostly 2012–2014) U.S. NEC (TWh/yr)	100% ENERGY STAR scenario (indeterminate future) UEC (kWh/yr)	100% ENERGY STAR scenario (indeterminate future) U.S. NEC (TWh/yr)
Receivers		6.4	65	0.7	47	0.5
Compact Audio		6.6	95	1.2	33	0.4
Blu-ray Players		0.2	15	1.7	15	1.6
DVD Devices		6.3	-	-	-	-
Game Consoles		15	199	13.2	46	3.1
Home Theatre in a Box (HTIB)		2.7	57	1.5	22	0.6
Radios		1.3	16	1.0	10	0.6
VCRs		2.7	-	-	-	-
Projectors		0.4	168	1.4	146	1.2
Camcorders		0.1	-	-	-	-
Digital Cameras		0.05	-	-	-	-
Digital Picture Frames		0.5	-	-	-	-
Mobile Phones		0.5	-	-	-	-
MP3 Player Docking Stations		1.2	25	1.2	14	0.7
Portable Audio		0.7	-	-	-	-
Audio and Other Consumer Electronics Subtotal*		**44.7**	**-**	**32.7**	**-**	**19.5**
Cordless Phones		2.2	1	0.2	1	0.2
Answering Machine - stand alone		0.3	-	-	-	-
VOIP Phones		1.6	4	0.2	3	0.2
VOIP Adaptor - stand alone		0.2	-	-	-	-
Mobile phone base stations		4.3	-	-	-	-
Femtocells		-	70	0.1	56	0.1
Telephony Subtotal*		**10.2**	**-**	**5.3**	**-**	**5.2**
Servers		29.3	-	-	-	-
Storage		6.95	-	-	-	-
Desktop PCs	257**	90	281	35.1	176	21.9
Notebook PCs	257**	8.3	65	7.7	45	5.3
Monitors	127	40	65	7.9	33	4
Personal Data Storage		0.8	10	0.1	4	0
Computer Speakers		2.8	-	-	-	-
Computers Subtotal*		**178.2**	**-**	**89.7**	**-**	**70.3**
Medical Imaging		6.8	59,245	-	39,497	-
Interactive Whiteboards		-	481	0.6	369	0.4
Professional Displays		-	-	-	-	-
Large Displays Subtotal		**0**	**-**	**0.6**	**-**	**0.4**
Small Network Equipment		7.1	36	8.2	30	6.7
Large Network Equipment		13.4	1230	4.9	651	2.6
Network Equipment Subtotal		**20.5**	**-**	**13.1**	**-**	**9.3**
Imaging Commercial		27.7	339	9.9	174	5.1
Imaging Residential		3.87	14	1.5	8	0.8
Imaging Equipment Subtotal		**31.6**	**-**	**11.4**	**-**	**5.9**
Set-top Boxes Cable		13	100	10.1	70	7.1
Set-top Boxes Satellite		8.5	87	6.7	65	5.0
Set-top Boxes Non-MVPD		2.4	27	1.7	20	1.3
Set-top Boxes Telco		1.8	104	5.4	94	4.9
Set-top Boxes Subtotal		**25.7**	**-**	**23.9**	**-**	**18.2**
Televisions	**117**	**68.6**	**111**	**22.4**	**89**	**17.9**
Grand Total (only products with ENERGY STAR data)		**323**		**145**		**92**
Grand Total*		**385**	**-**	**206**		**154**

* Publicly available data used for products without any ENERGY STAR data;
** Desktop and Notebook combined

- Electronics are 14% of buildings electricity (if data center energy use included in the "buildings" total—residential and commercial, again for the public estimate).
- The product types covered by ENERGY STAR account for 96% of electronics energy use.

Conclusions

The energy consumption of the electronics end use has risen dramatically over the last few decades, but concern that it will continue to do so may be unwarranted, in part due to the extensive efforts of public policy in this area, particularly those of the ENERGY STAR program. Despite the differences between the methodologies used to arrive at the three estimates, they do indicate a decreasing trend in UEC as more efficient technologies enter the market, which should result in the estimated NEC if the currently installed units are eventually replaced and neither shipments nor usage increase significantly.

More detailed attention to this topic is warranted, including tracking the adoption of more efficient products, retirement of less efficient products, changes in shipments, and changes in usage (e.g., second screens). Of particular interest are some of the niche (i.e., low shipment) product types, such as medical imaging, where the UEC is orders of magnitude larger than for consumer electronics, and where the total impact on NEC will greatly depend on usage and shipments. Also of interest is the movement of many product functions from the consumer device into "the cloud". As a result, the portion of consumption of data centers could rise, though the impact on total consumption is unknown and depends on the particulars of the implementation. Both trends show the growing impact of specialized products relative to consumer devices, which could change the focus of energy efficiency programs.

Another item for future work is a stronger focus on consistency when defining products to permit comparisons across time. Furthermore, even when product definitions are the same, it is important to ensure that all subtypes within the definition (e.g., very small and very large sizes) are included. Lastly, there is the issue of all the product types that were excluded even in this attempt at a comprehensive estimate. Future efforts could expand the analysis to include additional commercial electronics, while keeping up with new product types such as slates/tablets, soundbars, and wireless speakers.

Acknowledgments

We would like to express our appreciation to the authors of the public estimates we rely on for part of our analysis. We also rely on the work of many others at the EPA and contractors to EPA on ENERGY STAR.

References

Banerjee, N., A. Rahmati, M. D. Corner, S. Rollins, and L. Zhong. "Users and Batteries: Interactions and Adaptive Energy Management in Mobile Systems." UbiComp 2007. Innsbruck, Austria, 2007. 217-234.

Brown, R., W. Rittelmann, D. Parker, G. Homan, Appliances, Lighting, Electronics, and Miscellaneous Equipment Electricity Use in New Homes, Proceedings: 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

Brown, R., E. Masanet, B. Nordman, W. Tschudi, A. Shehabi, J. Stanley, J. Koomey, D. Sartor, P. Chan, J. Loper, S. Capana, B. Hedman, R. Duff, E. Haines, D. Sass, and A. Fanara. Report to Congress on Server and Data Center Energy Efficiency: Public Law 109-431. Lawrence Berkeley National Laboratory, Berkeley, California. LBNL-363E (2007).

CEA (Consumer Electronics Association). "CEA Consumer Electronics Detailed Forecast Module 2010-2015: Total U.S. Market." 2012.

———. "CEA Consumer Electronics Detailed Forecast Module 2011-2016: Total U.S. Market." 2013.

EIA, Energy Information Administration. Accessed May 31, 2013, data for 2010. http://www.eia.gov/electricity/annual/html/epa_02_02.html

EPA (Environmental Protection Agency). "ENERGY STAR Specifications At-a-Glance." November 20, 2012. Accessed March 1, 2014. https://www.energystar.gov/ia/partners/prod_development/downloads/Spec_At-A-Glance_PD.pdf .

———. "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2011 Summary." 2011.

———. "ENERGY STAR® Unit Shipment and Market Penetration Report Calendar Year 2012 Summary Report." 2012.

Koomey, J.G., “Growth In Data Center Electricity Use 2005 To 2010”, Analytics Press, 2011, available online at http://www.analyticspress.com/datacenters.html.

Lanzisera, S., B. Nordman and R. E. Brown, “Data network equipment energy use and savings potential in buildings”, *Energy Efficiency*, Volume 5, Number 2 (2012), 149-162.

McKenney, K., M. Guernsey, R. Ponoum, J. Rosenfeld, “Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type”, Final Report by TIAX LLC, No. D0498 for DOE, Building Technologies Program, May 2010.

Nordman, B., and M. Sanchez 2006. “Electronics Come of Age: A Taxonomy for Miscellaneous and Low Power Products.” Proceedings: 2006 ACEEE Summer Study on Energy Efficiency in Buildings.

Urban, B., V. Tiefenbeck, and K. Roth. “Energy Consumption of Consumer Electronics in U.S. Homes in 2010”. Final Report by Fraunhofer Center for Sustainable Energy Systems for the Consumer Electronics Association, 2011.