Calendar Year 2007 Program Benefits for U.S. EPA Energy Star Labeled Products: Expanded Methodology

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DISCLAIMER

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Executive Summary

Energy Star is a voluntary energy efficiency-labeling program operated jointly by the United States Department of Energy (U.S. DOE) and the United States Environmental Protection Agency (U.S. EPA). U.S. DOE and U.S. EPA enter into partnerships with manufacturers and key stakeholders to promote products that meet energy efficiency and performance criteria established by the agencies. The Energy Star label allows consumers to more easily identify and purchase energy-efficient products. By transforming the market for high-efficiency products, U.S. DOE and U.S. EPA reduce air pollution and greenhouse gases associated with energy consumption. Since the program inception in 1992, Energy Star has become a leading international brand for energy efficient products. Energy Star's central role in the development of regional, national, and international energy programs necessitates an open process whereby its program achievements to date, as well as projected future savings, are shared with stakeholders and the public.

Energy Star consists of three programmatic areas: products, buildings and industrial plants, and homes. This report focuses only on labeled products that are administered by the U.S. EPA, such as office equipment, appliances, and electronics. It does not cover savings for buildings and industrial plants, homes, or labeled products administered by U.S. DOE. The methodologies for quantifying savings for these other Energy Star program segments are significantly different than the methodology (for U.S. EPA-labeled products) outlined in this report, and cannot be addressed here in adequate detail.

Numerous supporting stakeholders, including utilities, regional energy partnerships, energy consortia, and nonprofit organizations, leverage the Energy Star program nationally. All stakeholders work toward advancing Energy Star goals, improving Energy Star consumer awareness, and promoting the sales of Energy Star products. This report provides a top-level summary of national savings achieved by Energy Star voluntary product labeling and does not make an attempt to attribute the national savings across federal, regional, state, and/or local efforts.

Today, U.S. EPA Energy Star includes over forty individually labeled products and has implemented over 70 specification revisions. To best quantify and analyze savings for all products, we developed a bottom-up product-based model. Each Energy Star product type is characterized by product-specific inputs that result in a product savings estimate. Energy Star program impacts are the sum of the impacts for each individual Energy Star product type. The bottom-up model allows us to separately evaluate the implementation process for each product type and quantify Energy Star's impact within each market. The model results inform U.S. EPA's product development strategy by providing valuable feedback regarding existing Energy Star market share and untapped market potential, a ranking of savings by product type, and impacts of ongoing specification revisions. Since Energy Star specifications are often a key component of many regional energy efficiency efforts, the bottom-up model allows U.S. EPA to provide critical product data to facilitate the development of localized programs.

Our model tracks carbon savings, energy savings, monetary savings, net monetary savings (monetary savings minus the incremental investment cost of realized savings), and peak power reductions for the analysis period 1993–2025. We track these indicators on an annual basis and also generate cumulative results over several time periods. The fundamental model output is a "best-estimate" result for Energy Star achievement to date and forecasted savings. In developing the model, we identified four target areas of uncertainty: annual Energy Star unit sales, office equipment power management success rates, marginal carbon factors, and forecasted energy prices. To address this uncertainty, we run sensitivity tests on these four key variables. Results from these sensitivity scenarios are used to bracket our best-estimate result.

Although the model is complex in terms of the number of products included and the number of inputs involved, the model structure and approach is streamlined, straightforward, and consistent. For all products, the approach for calculating carbon savings in a given year includes:

- A best estimate of the Energy Star installed base (stock) directly attributable to U.S. EPA program efforts
- A best estimate unit energy savings (UES) for the stock of ENERGY STAR units in place and attributable to U.S. EPA
- An applicable fuel-specific carbon factor

The UES for any given product can be summarized by one of three main approaches:

- Electronic modal-based: electronic products whose primary function is to process, display, or deliver information. Annual energy consumption is characterized by multiple modes of operation (e.g., *active, low power,* or *off*)
- Duty cycle-based: non-electronic modal products whose annual energy consumption is calculated from detailed power and usage inputs and typically includes only one mode
- Exogenous annual UEC: products whose annual consumption is a single value (with no details on product power and usage), taken from an exogenous source

In terms of input data collection for each product, we focus universally on the following key areas:

- Product-based framework: ensure it is complementary to Energy Star product specification structure
- Energy Star unit sales: ensure actual versus estimated sales whenever data is available
- Baseline assumptions: ensure assumptions capture market trends in the absence of the program and are product specific
- Modeling inputs: ensure data represents most current sources, draws on actual or measured versus estimated data when possible, and ensure energy inputs are product relevant

Our results show that through 2007, U.S. EPA Energy Star labeled products saved 5.5 Quads of primary energy and avoided 100 MtC of emissions. Although Energy Star-labeled products encompass over forty product types, only five of those product types accounted for 65% of all Energy Star carbon reductions achieved to date, including (listed in order of savings magnitude)

monitors, printers, residential light fixtures, televisions, and furnaces. The forecast shows that U.S. EPA's program is expected to save 12.2 Quads of primary energy and avoid 215 MtC of emissions over the period of 2008–2015. Monitors, printers, residential light fixtures, computers, and televisions account for about 60% of future carbon avoided. The sensitivity analysis bounds the best estimate of carbon avoided between 66 MtC and 131 MtC (1993–2007) and between 140 MtC and 290 MtC (2008–2015).

General limitations to our bottom-up model occur in two main areas: (1) the model requires numerous detailed inputs to generate the end result, and (2) uncertainty in those inputs is additive through the process. These limitations mean that collecting and documenting high-quality inputs (a potentially labor-intensive and expensive process) is essential. As a result, identifying areas of critical uncertainty and sensitivity and then targeting data collection and verification activities at those areas is key to obtaining reliable results. While all aspects of the input data are regularly updated, we focus additional resources on the office equipment product category, due to the large energy savings potential, as well as on consumer electronics, where usage patterns are more uncertain and new field data are becoming increasingly available.

This report is structured to include an expanded description of the methodology that focuses as much on the means and methods behind the results as the results themselves. The report includes a detailed overview of the methodology used to quantify U.S. EPA Energy Star product savings, a quantitative summary of U.S. EPA Energy Star product labeling achievements, and a discussion of limitations to our methodology and planned improvements. We present annual results for energy savings, peak load savings, carbon savings, and monetary savings for calendar years 2007, 2008, and 2009. Although the model results extend through 2025, we present cumulative results for energy savings, carbon savings, and monetary savings over the period 1993–2015 to minimize uncertainty inherent in an extended forecast.

The report covers five broad areas including:

- Introductory (Sections 1–3)
- Model Overview (Sections 4 and 5)
- Product Methodologies (Section 6)
- Results (Sections 7 and 8)
- Conclusions (Section 9)

1. Introduction and Study Objectives

Energy Star® is a voluntary labeling program operated jointly by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (U.S. EPA). The U.S. DOE and U.S. EPA enter into partnerships with manufacturers and key stakeholders to promote products that meet energy efficiency and performance criteria established by the agencies. The Energy Star label allows consumers to more easily identify and purchase energy-efficient products. By transforming the market for high- efficiency products, DOE and U.S. EPA reduce air pollution and greenhouse gases associated with energy consumption. For a more detailed description of the Energy Star program, refer to McWhinney et al. (2005), Brown et al. (2002), and www.energystar.gov. This report addresses the following areas related to U.S. EPA Energy Star-labeled products:

- Quantifying Energy Star impacts
- Identifying Energy Star achievements
- Describing methodological limitations in the analysis

We begin by providing an overview of our methodology and then present a discussion of analysis results.

2. Report Scope

Energy Star consists of three programmatic areas:

1. products,
2. buildings and industrial plants, and
3. homes.

Complete descriptions of these program areas can be found at www.energystar.gov. This report focuses only on labeled products that are administered by the U.S. EPA, such as office equipment, appliances, and electronics. It does not cover savings for buildings and industrial plants, homes, or labeled products administered by U.S. DOE. The methodologies for quantifying savings for these other Energy Star program segments are significantly different than the methodology for U.S. EPA-labeled products outlined in this report, and those other methodologies cannot be addressed here in adequate detail. See Horowitz (2001, 2004, 2007) for a complete summary of program impacts for Energy Star buildings. See U.S. EPA (2007a) for a summary of program impacts for Energy Star homes and industrial plants.

Table 2-1 shows Energy Star product types. For each product type, we list the year the program started and the dates of subsequent specification revisions. Full eligibility requirements for each product can be found at www.energystar.gov.

Table 2-1. Summary of Energy Star Products: Specifications and Effective Dates

Product types included in analysis	Original Spec.	Specification Revision Dates
Audio[1] and DVD[2]	1999	2003
Battery charging system	2006	
Boiler	1996	2002
CAC/ASHP[2]	1995	2002, 2006, 2009
Ceiling fan	2002	2003, 2006
Commercial dishwasher	2007	
Commercial fryer	2003	
Commercial hot food holding cabinet	2003	
Commercial solid door refrigerator and freezer	2001	2009 (proposed)
Commercial steam cooker	2003	
Computer	1992	1995, 1999, 2000, 2007, 2009 (proposed)
Copier	1995	1997, 1999, 2007, 2009 (proposed)
Decorative light strand	2008	
Dehumidifier	2001	2006, 2007, 2008
Digital TV Adapter	2007	
Exit sign[3]	1996	1999, 2004, 2008
External power adapter	2005	2008
Facsimile machine	1995	1995, 2000, 2001, 2007, 2009 (proposed)
Furnace	1995	2006, 2009 (proposed)
Geothermal HP[2]	1995	2001
Ice machine	2008	
Light commercial HVAC[2]	2002	2004
Monitor	1992	1995, 1998, 1999, 2005, 2006
Multifunction device	1997	1999, 2007, 2009 (proposed)
Printer	1993	1995, 2000, 2001, 2007, 2009 (proposed)
Programmable thermostat[3]	1995	*2008, 2009 (proposed)
Residential light fixture	1997	2001, 2002, 2003, 2005, 2008
Roof product	1999	2005, 2007
Room air cleaner	2004	
Scanner	1997	2007, 2009 (proposed)
Set-top box[3]	2001	*2005, 2009
Telephony	2002	2004, 2006, 2008
Television/VCR[2]	1998	2002, 2004, 2005, 2008
Traffic signal[3]	2000	2003, *2007
Transformer[3]	1995	*2007
Vending machine	2004	2006, 2007
Ventilation fan	2001	2003
Water cooler	2000	2004
Product types not included in analysis[4, 5]		
Buildings and industrial plant[5]	1991	1995, 1999, 2000, 2001, 2002, 2004, 2006
Compact fluorescent lamp (CFL)[6]	1999	2001, 2004, 2008
Home performance	2000	2002
Insulation[7]	1995	*2002

Table 2-1. (Continued)

Product types not included in analysis[4, 5]	Original Spec.	Specification Revision Dates
New home	1995	1997, 2006
Refrigerator and freezer[6]	1996	2001, 2003, 2004, 2008
Residential clothes washer[6]	1997	2001, 2004, 2007, 2009, 2011
Residential dishwasher[6]	1996	2001, 2007
Room air conditioner[6]	1996	2000, 2003, 2005
Window, door, and skylight[6]	1997	2003, 2005, 2009 (proposed)

Source: U.S. EPA (2008a)
Proposed specification changes are not included in this analysis.

Notes to Table 2-1:
1) *Audio* includes compacts disc (CD), mini-system, audio separate, and home theater in a box.
2) DVD = digital versatile disc, CAC = central air conditioning, ASHP = air source heat pump, HP = heat pump, HVAC = heating ventilation and air conditioning, VCR = video cassette recorder.
3) Specification revisions that resulted in program suspension are indicated with an asterisk (*). The set-top box standard was suspended in 2004 and then re-launched in 2009. The programmable thermostat standard is scheduled for sunset pending the 2009 specification revision outcome.
4) Building and Industrial Plant, New Home, and Home Performance programs are administered by U.S. EPA but are not included in this analysis due to a different program benefits methodology.
5) Changes to Energy Star building and industrial plant reflect building types or manufacturing sectors added to the program.
6) These are DOE-labeled products.
7) The insulation specification was revised in 2002 and insulation was incorporated into Home Performance with Energy Star.

Our study tracks energy savings, carbon savings, monetary savings, net monetary savings (that is, monetary savings minus the incremental investment cost of realized savings), and peak power reductions for the analysis period 1993–2025. We track these indicators on an annual basis and also generate cumulative results over several time periods. In this report, we present annual results for energy savings, peak load savings, carbon savings, and monetary savings for calendar years 2007, 2008, and 2009. Although the model results extend through 2025, we present cumulative results for energy savings, carbon savings, and monetary savings over the period 1993–2015 to minimize uncertainty inherent in an extended forecast.

3. Program Attribution

Numerous supporting stakeholders, including utilities, regional energy partnerships, energy consortia, and nonprofit organizations, leverage the Energy Star program nationally. All stakeholders work toward advancing Energy Star goals, improving Energy Star consumer awareness, and promoting the sales of Energy Star products. This report provides a top-level summary of national savings achieved by Energy Star voluntary product labeling and does not make an attempt to attribute the national savings across federal, regional, state, and/or local efforts.

4. Technical Approach

4.1. Bottom-up Approach

We employ a bottom-up methodology for quantifying savings for Energy Star-labeled products. Each Energy Star product type is characterized by product-specific inputs that result in a product savings estimate. Therefore, Energy Star program-level impacts are the sum of the impacts for each individual Energy Star product type. The bottom-up model allows us to separately evaluate the implementation process for each product type and quantify Energy Star's impact within each market. Since Energy Star specifications are often a key component of many regional energy efficiency efforts, the bottom-up model allows U.S. EPA and U.S. DOE to distribute critical product data to facilitate the development of localized programs.

We implement the bottom-up model with awareness that uncertainty for each product type contributes to uncertainty in total Energy Star impacts. This means that many small inaccuracies are additive overall and any one inaccurate estimate for a product type with large energy savings can significantly affect the overall results. To address uncertainty, we run sensitivity tests on key variables, including Energy Star unit sales, energy prices, and carbon emission factors.[1] While all aspects of the input data are regularly updated, we focus additional resources on the office equipment product category, due to the large energy savings potential, as well as on consumer electronics, where usage patterns are more uncertain and new field data are becoming increasingly available (Porter et al. 2006; Nordman and McMahon 2004; Roth and McKenny 2007).

In cases where other organizations have collected market and engineering data pertaining to Energy Star product types, we integrate the data as applicable. We also work with the DOE's Energy Information Administration (EIA) to harmonize inputs with the National Energy Modeling System (NEMS), which is used to generate national energy forecasts at both the sector and end-use level. In particular, we share data on product power consumption, usage, total energy, and Energy Star market shares for product types that are individually treated in both models. These product types include residential heating and cooling equipment, televisions and set-top boxes, home computers, commercial office equipment, and lighting.

4.2. General Analysis Overview

We begin the analysis by segmenting sales of each product type into non-Energy Star and Energy Star units. Manufacturer partners report Energy Star unit sales to U.S. EPA each calendar year.[2] In 2007, partners reported Energy Star sales for all U.S. EPA-labeled products except thermostats, personal computers (PCs), facsimile machines, scanners, printers, copiers, and multi-function devices (MFDs), due to partner requirements specified in their existing

[1] The sensitivity analysis in Section 6.7.2 includes varying carbon inputs. We do not present monetary or energy results for price and heat rate sensitivity.

[2] Energy Star unit sales data have been collected from manufacturer partners as part of the Energy Star Program requirements for calendar years 2002–2007 (ICF 2003, 2004, 2006a, 2006b, 2007, 2008). Energy Star sales data for earlier years and subsequent forecast years are based on industry and market data.

partnership agreements. Market shares for these non-reported products are Lawrence Berkeley National Laboratory (LBNL) estimates based on market research reports and industry estimates (Gartner 2001). Manufacturers will begin reporting Energy Star sales for PCs and imaging equipment for calendar year 2008.

Table 4-1 shows actual Energy Star unit sales for 2007 and projected Energy Star unit sales for 2008.

Sales of Energy Star units are further divided into Energy Star unit sales attributed to program efforts and Energy Star unit sales not attributed to program efforts (referred to as *free riders* throughout the report). At each product launch, we set a reference case program penetration equal to the market share of products that meet the final Energy Star performance criteria at the time of the agency's initial product development efforts. This initial Energy Star reference case penetration is calculated using the model-specific energy consumption test data collected by the agency at the start of its product development effort. In most product cases, the reference case penetration is equal to the free rider penetration. This means that all units that meet the qualifying criteria during product development actually do participate once the program is effective.

There are some cases where the free rider penetration is actually lower than our reference case penetration. This scenario exists where program participation is extremely low despite the prevalence of high-efficiency units, which could indicate a lack of interest or that other non-Energy Star based efforts are more important to the product market (e.g., federal standards, utility rebates, procurement efforts). In this case, we model our non-Energy Star baseline by adding these units as a market segment of high-efficiency non-Energy Star units (see Section 5).

Table 4-1. Actual U.S. EPA Energy Star Market Shares for 2007 and Projected U.S. EPA Energy Star Market Shares for 2008

	Actual 2007			**Projected 2008**		
Equipment Type	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share
	1000s	1000s	%	1000s	1000s	%
Office Equipment						
-Office Copier	663	1,325	50	932	1,332	70
-Office Facsimile	141	281	50	184	263	70
-Office Printer	3,313	6,626	50	4,583	6,548	70
-Office Scanner	1,530	3,060	50	2,121	3,029	70
-Office Multi-function	8,647	17,299	50	12,647	18,153	70
-Office CRT	78	727	11	50	353	14
-Office LCD	23,380	24,640	95	23,581	24,852	95
-Office PC	40,120	41,042	98	10,936	44,044	25
-Residential Copier	0	0	NA	0	0	NA
-Residential Facsimile	415	830	50	546	779	70
-Residential Printer	3,066	6,132	50	3,892	5,560	70
-Residential Scanner	2,628	5,256	50	3,642	5,203	70
-Residential Multi-function	1,269	2,538	50	1,858	2,654	70
-Residential CRT	53	499	11	75	251	30
-Residential LCD	16,074	16,940	95	16,810	17,716	95
-Residential PC	27,401	53,733	51	7,672	57,385	13
Consumer Electronics						
-TV	16,649	31,680	53	19,177	32,670	59
-VCR	0	751	0	0	744	0
-TV/VCR/DVD	802	6,578	12	814	6,536	12
-DVD Player	8,395	19,590	43	8,815	19,394	45
-Mini-System	351	3,905	9	368	3,903	9
-Home Theater	800	2,723	29	681	2,720	25
-Audio Separates	762	2,064	37	763	2,062	37
-Compact Disc Player	0	598	0	0	598	0
-Answering Machine	0	1,182	0	0	1,170	0
-Cordless Phone	1,850	13,620	14	1,841	13,483	14
-DSS Cordless Phone	412	3,032	14	750	3,001	25
-Combination Phone	4,192	12,307	34	4,171	12,431	34
-DSS Combination Phone	3,191	9,370	34	3,247	9,277	35
-Additional Handset	160	1,224	13	159	1,211	13
-Digital TV Adapter	0	0	NA	0	0	NA
-Set-top Box	0	20,528	0	0	23,429	0
-External Power Supply	312,041	554,710	56	315,335	565,704	56
-Battery charger	6,505	41,255	16	6,602	41,668	16

Table 4-1. (continued)

Equipment Type	Actual 2007			Projected 2008		
	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share
	1000s	1000s	%	1000s	1000s	%
Heating and Cooling						
-Air Source Heat Pump	385	2,151	18	391	2,178	18
-Geothermal Heat Pump	99	108	92	100	161	62
-Central Air Conditioner	1,032	5,000	21	1,048	5,050	21
-Gas Furnace	1,031	3,248	32	1,046	3,300	32
-Oil Furnace	10	100	10	11	100	11
-Gas Boiler	76	196	39	77	196	40
-Oil Boiler	99	162	61	101	162	62
-Unitary HVAC (10^6 ft^2)	261	741	35	284	750	38
-Thermostat	2,432	6,538	37	2,549	6,610	39
Residential and Commercial Lighting						
- Indoor Fixture	10,810	189,263	6	11,351	191,156	6
- Outdoor Fixture	4,781	28,619	17	5,020	28,905	17
- Exit Sign	NA	NA	NA	NA	NA	NA
- DLS	NA	NA	NA	37,700	125,668	30
- Traffic Signal	NA	NA	NA	NA	NA	NA
Residential Appliance						
-Dehumidifier	1,151	2,000	58	933	2,034	46
-Air Cleaner	361	2,505	14	391	2,567	15
-Exhaust Fan	805	6,354	13	859	6,432	13
-Ceiling Fan Only	2,647	7,709	34	2,917	7,760	38
-Ceiling Fan with Light Kit	132	9,970	1	145	10,045	1
-Light Kit for Ceiling Fan	21	2,151	1	23	2,167	1
Commercial Appliance						
-Vending Machine	64	246	26	69	246	28
-Hot Food Holding Cabinet	20	114	17	23	116	19
-Steamer	5	41	12	7	42	17
-Fryer	6	85	7	7	86	8
-Commercial Refrigeration	147	240	61	149	242	62
-Water Cooler	624	1,201	52	633	1,264	50
-Ice Machine	NA	NA	NA	24	162	15
-Dishwasher	NA	NA	NA	6	38	15

Table 4-1. (continued)

Equipment Type	Actual 2007			Projected 2008		
	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share	Total Energy Star Shipments	Total U.S. Shipments	Energy Star Market Share
	1000s	1000s	%	1000s	1000s	%
Other						
- Utility Transformer	NA	NA	NA	NA	NA	NA
- C&I Transformer	NA	NA	NA	NA	NA	NA
- Residential Roofing (10^9 ft^2)	0	5	9	0	5	9
- Commercial Roofing (10^9 ft^2)	2	16	10	2	16	10

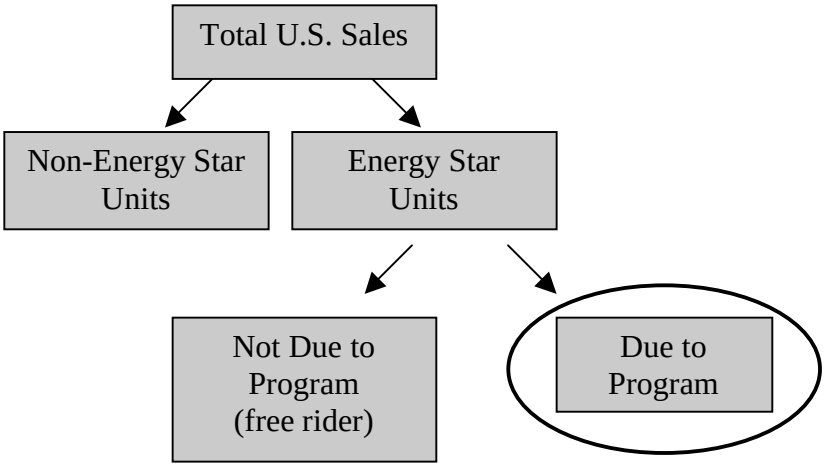
Notes to Table 4-1:

1) Energy Star market share column values may not sum to equal shipment values due to rounding.
2) 2007 Energy Star units are from ICF (2008), with the exception of the following products: residential and office copier, fax, printer, scanner, MFD, and PC are extrapolated from Gartner (2001). Thermostat market shares are industry estimates provided by Honeywell.
3) Energy Star exit sign, traffic signal, and transformer are discontinued. (program savings continue to accrue due to existing stock).
4) Residential PC include desktop, laptop, and video game.
5) Office PC include desktop, laptop, and workstation.
6) Unitary HVAC is expressed in million square feet.
7) Roofing is expressed in billion square feet.
8) PC market shares in 2008 reflect the revised computer specification.
9) Digital TV adapter is modeled as sales in 2009.
10) Projected 2008 market shares are LBNL best estimates, taking into consideration past Energy Star unit sales, new product launches, Energy Star specification revisions, and trends in total U.S. sales.
11) New specifications for DLS, commercial ice machine and dishwasher are effective in 2008.
12) CRT = cathode ray tube, LCD = liquid crystal display, DSS = digital signature standard, DLS = decorative light string, and C&I = commercial and industrial.

Energy Star unit sales attributed to the program are calculated as the total Energy Star unit sales in any given year minus Energy Star unit free riders. Energy Star savings include only the savings for Energy Star units directly attributed to the program. Figure 4-1 illustrates the sales segmentation.

Figure 4-1. Market Segmentation of Energy Star Products

(products in the circle accrue savings for the program).



We next estimate a unit energy consumption (UEC) for both non-Energy Star and Energy Star units. Our non-Energy Star UEC is comprised of reference case efficiency units that do not meet the Energy Star requirement (REF or REF UEC) and (when applicable[3]) high-efficiency non-Energy Star units that meet or exceed the Energy Star requirement but do not participate in the program. The non-Energy Star baseline is characterized by a UEC and a market share for each efficiency segment. Non-Energy Star efficiency improvements can be modeled directly as a change in the UEC of either of these segments. We can also model non-Energy Star efficiency improvements as a shift over time from REF units to high-efficiency non-Energy Star units.

The Energy Star UECs for office equipment and consumer electronics are estimated to be the average UEC of Energy Star-qualified products sold in the market in a given year based on manufacturer energy consumption test data for qualified products and independent field testing. For all other product types, the Energy Star UEC is calculated based on the minimum program requirements.

The unit energy savings (UES) for each product type is the difference between the non-Energy Star UEC and the Energy Star UEC in a given year. The UES for most product types changes over time due to specification revisions, usage pattern changes, and changes to the non-Energy Star efficiency. To account for this variation, we calculate the energy savings for each year's Energy Star sales and then use a retirement function to add up the savings for all the equipment vintages in place in a given year. We assume that Energy Star units remain in service and accrue savings for a period equal to the average product lifetime.

Aggregate energy bill savings are estimated using year-by-year energy prices from DOE, as shown in Table 4-2. Energy bill savings are discounted at a 4% real discount rate. Carbon emissions reductions are calculated from energy savings using year-by-year carbon emissions factors. For electricity, we use U.S. EPA's national average marginal carbon factor, which is

[3] *When applicable* refers to a product case where free rider market share is lower than the estimated reference case market share of units that meet or exceed Energy Star requirements.

derived from models used as part of the U.S. government's reporting requirements under the United Nations Framework Convention on Climate Change and historical emissions data from the U.S. EPA's Emissions and Generation Resource Integrated Database (eGRID). Forecasted marginal carbon factors are derived from energy-efficiency scenario runs of the integrated utility dispatch model (IPM®) (U.S. EPA 2007b). Carbon factors for natural gas and oil are assumed to be constant throughout the period at 14.4 kg C/MBtu for natural gas and 19.75 kg C/MBtu for oil. Heat rates are average rates and not marginal.

Table 4-2. Best Estimate Energy Prices and Carbon Factors by Year (2007 dollars)

Year	Electricity Price Comm.	Resid.	Gas Price Comm.	Resid.	Oil Price	C emissions factor for electricity[2, 3]	Electric Heat Rate	Price and Electric Heat Rate Source, US DOE[1]
	($/kWh)[4]		($/MBtu)		($/MBtu)	(MtC/TWh)	(Btu/kWh)	(year)
1993	0.105	0.113	6.78	8.05	8.87	0.203	11,019	1996a
1994	0.104	0.112	7.09	8.30	8.43	0.203	10,948	1996b
1995	0.097	0.109	6.46	7.74	8.15	0.203	10,970	1997
1996	0.096	0.107	6.71	7.88	9.01	0.203	10,866	1998
1997	0.094	0.104	7.08	8.47	8.86	0.203	10,978	1999
1998	0.092	0.101	6.69	8.24	7.64	0.203	10,891	2000
1999	0.087	0.099	6.39	7.96	7.65	0.203	10,784	2001
2000	0.087	0.098	7.76	9.06	11.30	0.203	11,181	2003
2001	0.092	0.100	9.69	10.95	10.44	0.203	11,030	2003
2002	0.090	0.097	7.45	8.79	9.41	0.203	11,008	2005
2003	0.089	0.097	9.03	10.31	10.77	0.203	10,997	2006
2004	0.089	0.098	9.96	11.35	13.65	0.203	10,952	2007
2005	0.091	0.100	11.83	13.20	17.44	0.203	10,861	2008
2010	0.098	0.110	10.88	12.48	17.66	0.190	10,717	2008
2015	0.089	0.105	9.93	11.50	14.65	0.190	10,623	2008
2020	0.090	0.106	10.17	11.70	14.66	0.190	10,609	2008
2025	0.090	0.106	10.75	12.25	15.54	0.190	10,552	2008

kWh = kilowatthour; TWh = terawatthour; MBtu = Million Btu; MtC = Metric tons of Carbon**.**
Comm = commercial; Resid = residential.

Notes to Table 4-2:

1) U.S. DOE refers to U.S. DOE Annual Energy Outlook (AEO), published by the Energy Information Administration. The publication year for the applicable AEO is listed in the table. Full citations are found in the references section.
2) Carbon coefficients for natural gas and oil are assumed to be constant throughout the period at 14.4 kilograms of carbon per million British thermal units (kg C/MBtu) for natural gas and 19.75 kg C/MBtu for oil. Carbon emissions factors for electricity are marginal, not average.
3) Carbon emission factors (1993–2005) are from the Cadmus Group (1998); carbon emission factors 2010 and 2025 are from U.S. EPA (2007b).
4) All prices have been converted to 2007 dollars using implicit gross domestic product deflators from the U.S. Department of Commerce (2007).
5) Heat rates are average heat rates.

Equation 4-1 summarizes our calculation methodology for estimating Energy Star savings for a single product type in year *t:*

Equation 4-1. Energy Star annual energy savings in year *t*

$$\text{Annual Energy Savings in Year t} = \sum_{n=t-L}^{t} X_n UES_n$$

$$\text{Annual Energy Bill in Year t (Undiscounted)} = AES_t P_t$$

$$\text{Annual Carbon Savings in Year t} = AES_t C_t$$

where

X_n = The number of Energy Star units sold in year n due to the program

UES_n = The unit energy savings of Energy Star units sold in year n (in kWh or MBtu)

L = product lifetime

AES_t = The aggregate annual energy savings in year t (in kWh or MBtu)

P_t = The energy price in year t (in $/kWh or $/MBtu)

C_t = The carbon emissions factor in year t (in kg/kWh or kg/MBtu)

4.3. Market Transformation Approach

Energy Star has implemented over fifty specification revisions for product types included in this analysis. With each specification revision, Energy Star unit sales typically decrease due to the tightened requirements until manufacturers institute product design changes to meet the revised requirements. The initial decline in Energy Star unit sales results in a cohort of units that met the Energy Star criteria under the previous specification but do not meet the revised Energy Star requirements. We calculate the number of these "former" Energy Star units as the difference between Energy Star unit sales in the year preceding a specification change and the actual Energy Star unit sales in subsequent years when the new specification is effective.

Some complexities arise by focusing the market transformation methodology on maintaining stable annual shipments of high-efficiency units due to the Energy Star program. While this methodology is predictable for products with stable U.S. sales, this methodology is less capable of capturing products with increasing, decreasing, or volatile U.S. sales. For products with declining sales, the methodology assumes that "inefficient" units are the ones phased-out of the market such that overall market penetration of U.S. EPA-credited products actually increases over time. For products with increasing sales, the methodology assumes that incremental new sales are manufactured with no regard to U.S. EPA's program, such that the market penetration of U.S. EPA-credited products actually declines over time. Products with volatile sales are most problematic, and the methodology yields a combination of results, depending on whether the unit sales decline or increase in a given year.

Table 4-3 illustrates a hypothetical application of this methodology. U.S. EPA realizes savings for unit sales meeting the previous specification until Energy Star unit sales under the revised specification meet or exceed Energy Star unit sales under the previous specification.

We refer to this component of our methodology as a *market transformation effect.* This methodology assumes that units that met previous Energy Star levels continue to be in compliance with previous levels despite no longer being labeled Energy Star (i.e., manufacturers do not change the design of these previously qualified products to be less efficient). To date, non-qualified model energy consumption test data submitted by manufacturers to the agency during a subsequent specification revision support this assumption.

Equation 4-2 summarizes our calculation methodology for estimating Energy Star savings for a single product type in year *t* when the market transformation effect is applicable:

Equation 4-2. Calculations for estimating Energy Star savings (in year *t* with market transformation)

The total shipments due to program in any given year *n* for the current Energy Star specification version *v,* is equal to:

$$X_n = \sum_{r=1}^{v_n} X_r$$

where

X_n = The number of high efficiency units due to program in year n

X_r = The number of high efficiency units due to Tier r in year n

The average UES in any given year *n,* is equal to:

$$UES_n = \sum_{r=1}^{v_n} X_r * UES_r \div X_n$$

where

UES_n = The unit energy savings of high efficiency units due to program in year n

X_r = The number of high efficiency units due to Tier r in year n

X_n = The number of high efficiency units due to the program in year n

UES_r = The unit energy savings of high efficiency units due to Tier r in year n

The annual savings in a given year *t* are equal to:

$$\text{Annual Energy Savings in Year } t = \sum_{n=t-L}^{t} X_n UES_n$$

$$\text{Annual Energy Bill in Year } t \text{ (Undiscounted)} = AES_t P_t$$

$$\text{Annual Carbon Savings in Year } t = AES_t C_t$$

where

X_n = The number of high efficiency units sold in year n due to the program

UES_n = The unit energy savings of high efficiency units sold in year n (in kWh or MBtu)

L = product lifetime

AES_t = The aggregate annual energy savings in year t (in kWh or MBtu)

P_t = The energy price in year t (in $/kWh or $/MBtu)

C_t = The carbon emissions factor in year t (in kg/kWh or kg/MBtu)

where **v** is the current Tier of the Energy Star specification in year **t**.

Table 4-3. Hypothetical example of Energy Star market transformation methodology

	2002	2003	2004	2005	2006	2007	2008
Energy Star Unit Sales, Tier 1 (thousands)	300	440	600	340	180	0	0
Energy Star Unit Sales, Tier 2 (thousands)				260	420	600	800
Total Energy Star Unit Sales	300	440	600	600	600	600	800
UES Tier 1 (kWh/yr)	50	50	50	50	50	50	50
UES Tier 2 (kWh/yr)				80	80	80	80
Yearly Energy Savings for Current Year Sales only (kWh/yr)	15,000	22,000	30,000	37,800	42,600	48,000	64,000
Annual Energy Saved for Energy Star stock in current year (kWh/yr)	15,000	37,000	67,000	104,800	147,400	195,400	259,000

Notes to Table 4-3:

1) We refer to specification versions as *Energy Star Tiers*. Tier 1 corresponds to the original specification, and Tier 2 corresponds to the revised specification.

2) In this example, there were 600 Energy Star units sold in 2004 (the final year of the Tier I specification). In 2005, there were only 340 Energy Star units sold that met the revised Tier 2 specification. We calculate that 260 units (600 - 340) were sold in 2005 that continued to meet Tier 1 levels. We assume that the 260 units accrue savings equivalent to 50 kWh/year (the UES for Tier 3). This methodology is applied until 2007, when Energy Star units shipped under Tier 2 are equivalent to Energy Star units shipped under Tier 1 (in 2004).

We present a detailed analysis of the quantitative impact of market transformation in our results in Section 6.7.3.

4.4. Estimating Peak Load Reductions

For power system reliability, the electricity savings that matter most are those that occur when the power system is constrained, during periods of peak demand. In most parts of the country, peak demand is driven by high summer cooling loads. Energy Star central air conditioner savings tend to occur on peak, while the auto-off feature of Energy Star copiers tends to save energy off peak. Other products, such as TVs, accrue fairly level savings through peak and off-peak periods.

Peak power reductions are estimated from aggregate energy savings using a conservation load factor (CLF) that relates average load savings to peak load savings for a conservation measure. Conservation load factors were obtained from previous research (when available), developed from time-of-day metered data, or based on assumed time-of-day and seasonal operating patterns (if no metered data were available). A CLF of 1.0 indicates that energy savings are distributed evenly across peak and off-peak periods (e.g., Energy Star TVs). Conservation load factors of less than 1.0 indicate that savings are greater during peak periods (e.g., CLF of central air conditioners), while CLFs of more than 1.0 indicate that savings occur mostly off-peak (e.g., CLF of copier low-power and auto-off modes). Conservation load factor methodology is detailed in Koomey et al. (1990). CLFs, peak load savings, and sources are shown in Table 7-1, Table 7-2, and Table 7-3.

5. Savings Methodology Summary

This section presents detailed equations for calculating UECs by product type and then describes the process by which the UECs are used to derive UESs and annual program savings. The underlying product UECs are key components in the calculation of annual program savings.

Products in the report fall into one of three categories:

1. Electronic modal-based
2. Duty cycle-based
3. Exogenous annual UEC-based

Table 5-1 details the applicable calculation methodology for each product category.

Electronic modal-based products are products whose primary function is to process, display, or deliver information. Annual energy consumption is characterized by multiple modes of operation (e.g., *active*, *low power*, or *off*). Each mode is characterized by a power level and a usage pattern. Total annual energy is the summation of the annual electronic modal energy consumption. Details about the modes are shown in Table 5-2.

Duty cycle-based products are non-electronic modal products whose annual energy consumption is calculated from detailed power and usage inputs. Most duty cycle products are characterized by a single mode of operation.

Exogenous annual UEC products are those whose annual consumption is a single value (with no details on product power and usage) taken from an exogenous source.

The procedures for electronic modal-based and duty cycle-based products are described in Section 5.1 and 5.2, respectively. These two procedures show the calculation of a product-specific REF and Energy Star UEC in the year that it was sold (we denote this as year *n*). Energy consumption estimates for exogenous annual UEC products can be found in Section 6.

Table 5-1. Summary of UEC methodology by product

Product Category / Product	Electronic Modal	Duty Cycle	Exogenous Annual UEC
Audio and video (AV)			
Audio separates			X
VCR, DVD, VCR/DVD, CD, HTIB, Mini-System	X		
Battery Chargers[1]			
Battery Charger	X		X
External Power Supply (EPS)	X		X
Commercial cooking			
Fryers, hot food holding cabinets (HFHC), steamer		X	
Commercial dishwasher		X	
Commercial refrigeration			
Ice maker, vending machine		X	
Bottled-water cooler, refrigerator, freezer			X
Computer			
Desktop, notebook	X		
Workstation			X
Display			
Monitor, TVs	X		
HVAC			
Furnace, Boiler, CAC, ASHP, GeoHP, light commercial HVAC, thermostat			X
Imaging[2]			
Inkjet or Laser: printer, fax, scanner, copier, MFD	X		X
Lighting			
Fixture, Exit sign, DLS, Traffic signal		X	
Roofing[3]			X
Set-top Box[4]			
Digital Television Adapter (DTA)	X		
Cable, Satellite, IP			X
Small appliance			
Dehumidifier, room air cleaner		X	
Ceiling fan, ventilation fan			X
Telephony			
Answering machine, Cordless and Combination phone, Additional handset	X		
Transformer			
Commercial & Industrial, Utility		X	

Notes to Table 5-1:

1) External power supply and battery charger are categorized as electronic modal, duty-cycle, or exogenous annual UEC, depending on what equipment attaches to them.
2) Inkjet technology is electronic modal-based, and laser technology is exogenous annual UEC-based.
3) Roofing savings are based on a given UES. Details on the roofing methodology and UES values can be found in Section 6.11. No details are presented in Section 5.
4) Set-top box cable and satellite used an electronic modal calculation from 2001 through 2005 when the program was suspended. The specification was revised in 2009, at which point the calculation became exogenous annual UEC-based. DTA is electronic modal-based.

5.1. General Equations for Electronic Modal-based Products

There are two categories of electronic modal products: (1) those that have power management (PM) capability, and (2) those without PM capability.

Power management is a feature that allows a product to enter a low-power state when it has been left inactive. Some product types lack PM in their REF case and only have PM in their Energy Star case; these products are denoted by a dash in the last column of
Table 5-2, the electronic modal products list.

Electronic Modal Product with Power Management Capability

For a product with PM, there are five possible modes of operation:

- power managed and equipment turned off
- power managed and equipment left on
- power management turned off and equipment turned off
- power management turned off and equipment left on
- unplugged

The number of hours the product spends in each mode is calculated, and then the total hours are summed to arrive at the weighted UEC average. Weighted average REF UECs and weighted average Energy Star UECs vary, based on whether or not PM is included in the REF (see Section 6 for each product's detailed methodologies) and the applicable electronic modal power levels. The general equation for calculating the REF UEC and Energy Star UEC for each mode is shown in Equation 5-1.

Equation 5-1. General equation for electronic modal-based equipment UEC

$$UEC_n = \frac{\sum_{i=0}^{m} P_i * HY_i}{1000}$$

where

UEC_n = annual energy consumption for a unit turned off and PM enabled (kWh/yr)
m = the highest power-consuming mode (see
Table 5-2 for modes)
P_i = power consumption of a unit in mode *i* (W)
HY_i = annual operating hours in mode *i* (hour)

Table 5-3 shows in more detail how the electric modal product calculations account for the power management enabling rates and equipment turn-off rates.

Table 5-2. Electronic modal products list

	Electronic modal product types	Mode 0 standby	Mode 1 sleep	Mode 2 idle	Mode 3 active	Mode 4 charging, battery discharged	Mode 5 charging, battery full	PM in REF
With PM	Monitor	X	X	-	X	-	-	-
	Computer (desktop)	X	X	X	X	-	-	-
	Computer (laptop)	X	X	X	X	X	X	X
	STB (DTA)	X	X	-	X	-	-	X
	Imaging (copier)	X	X	X	X	-	-	X
	Imaging (all, excl. copier)	X	X	X	X	-	-	-
No PM	STB (all, excl. DTA)	X	-	-	X	-	-	-
	TV	X	-	-	X	-	-	-
	AV	X	-	X	X	-	-	-
	Telephony	X	-	-	X	X	X	-
	EPS	X	X	X	X	X	X	-

Notes to Table 5-2:
1) standby = lowest power-consuming mode (can be off or can be entered through power management standard).
2) active = processing (AV signals or data).
3) idle = lowered power consumption.
4) sleep = lowered power consumption (lower than idle, higher than standby).
5) If REF has no PM, then REF UEC does not have a sleep mode, and only the Energy Star unit has a sleep mode.
6) X = mode applicable; - = mode not applicable

Table 5-3. Electronic modal products PM and turn-off rates

Electric modal products	PM	Turn off	Mode 0	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Monitor	on	yes	X	X	-	X	-	-
	on	no	-	X	-	X	-	-
	off	yes	X	-	-	X	-	-
	off	no	-	-	-	X	-	-
Computer (desktop)	on	yes	X	X	X	X	-	-
	on	no	-	X	X	X	-	-
	off	yes	X	-	X	X	-	-
	off	no	-	-	X	X	-	-
Computer (laptop)	on	yes	X	X	X	X	X	X
	on	no	-	X	X	X	X	X
	off	yes	X	-	X	X	X	X
	off	no	-	-	X	X	X	X
STB (DTA)	on	yes	X	X	-	X	-	-
	on	no	-	X	-	X	-	-
	off	yes	X	-	-	X	-	-
	off	no	-	-	-	X	-	-
Imaging	on	yes	X	X	X	X	-	-
	on	no	-	X	X	X	-	-
	off	yes	X	-	X	X	-	-
	off	no	-	-	X	X	-	-

1) X = mode applicable; - = mode not applicable

For products with PM only in the Energy Star case (monitor, computer, imaging equipment excluding copier), the REF weighted average UEC is calculated according to Equation 5-2, and the Energy Star weighted average UEC is calculated according to Equation 5-3.

For products with PM in REF, both REF and Energy Star are calculated according to Equation 5-3.

Equation 5-2. Weighted average UEC equation (no PM, but turn-off rates apply)

$$UEC_{AVG} = UEC_{TO} * (1 - PER_{LO}) + UEC_{LO} * PER_{LO}$$

where for every year *n*

UEC_{AVG} = Weighted average annual energy for a unit (kWh/yr)
UEC_{TO} = Annual energy for a unit turned off after use (kWh/yr)
UEC_{LO} = Annual energy for a unit left on after use (kWh/yr)
PER_{LO} = Percent of units left on after use (%)

Equation 5-3. Weighted average UEC equation (PM and turn-off rates apply)

$$UEC_{AVG} = UEC_{PMTO} * (1 - PER_{LO}) * PM + UEC_{PMLO} * PER_{LO} * PM +$$
$$UEC_{TO} * (1 - PER_{LO}) * (1 - PM) + UEC_{LO} * (PER_{LO}) * (1 - PM)$$

where for year *n*

UEC_{AVG} = average annual energy consumption for a unit (kWh/yr)
UEC_{PMTO} = annual energy consumption for a unit turned off and PM enabled (kWh/yr)
UEC_{PMLO} = annual energy consumption for a unit left on and PM enabled (kWh/yr)
UEC_{TO} = annual energy consumption for a unit turned off and PM not-enabled (kWh/yr)
UEC_{LO} = annual energy consumption for a unit left on and PM not-enabled (kWh/yr)
PER_{LO} = percent left on after use (%)
PM = percent enabled (%)

Electronic Modal Product Without Power Management Capability

The weighted average UEC for products without PM capability is also calculated using Equation 5-1.

5.2. General Equations for Duty Cycle-based Products

The UEC for duty cycle-based products is calculated as the product of the energy rate (measured in Watts or Btu/h) and the time interval of delivery (often referred to as *duty cycle* or *operating pattern*).

Detailed UEC-based Product Calculation

The detailed UEC-based product calculation is summarized generally by Equation 5-4.

Equation 5-4. Duty-cycle UEC-based product calculation

$$UEC_n = P_n * HY_n$$

where

UEC_n = Annual energy consumption in year *n* (Wh/yr or Btu/yr)
P_n = Time rate of energy in year *n* (W or Btu/h)
HY_n = Time interval of delivery in year *n* (hrs/yr)

This calculation form applies to both REF and Energy Star, with the difference being that input values may differ between the two scenarios. Although Equation 5-4 is common to all duty-cycle UEC-based products, the specific inputs used to characterize power and usage varies across the different products.

We present detailed equations for each product described by this calculation approach.

Commercial Dishwasher

Commercial dishwashers are divided into two categories: low temperature (chemical sanitizing) and high temperature (hot water sanitizing with booster heater) units. Gas consumption is due to hot water usage, while electric consumption is due to the heater.

The UEC is calculated as follows:

Equation 5-5. Water requirement calculation

$$Water_n = GPR_n * Racks * Days$$

where

$Water_n$ = Annual water use in year *n* (gal/yr)
GPR_n = Gallons per rack in year *n* (gal/rack)
Racks = Racks per day (rack/day)
Days = Days in operation per year (day/year)

Equation 5-6. Idle electric consumption calculation

$$Idle_n = IR_n * IdleHR * Days$$

where

$Idle_n$ = Idle energy per year in year *n* (kWh/yr)
IR_n = Idle rate in year *n* (kW)
IdleHR = Idle hours per day (h/day)
Days = Days in operation per year (day/year)

Equation 5-7. Booster heater UEC calculation (only applies to high temp devices)

$$WaterE_n = (Water_n * DWater * SHWater * BDegrees) / 3412$$

where

$WaterE_n$ = Booster heater unit energy consumption in year *n* (kWh/yr)
$Water_n$ = Annual water use in year *n* (gal/yr)
DWater = Density of water (lb/gal)
SHWater = Specific heat of water (Btu/lb-degree Fahrenheit)
BDegrees = Temperature rise in booster tanks (Fahrenheit)

Note that booster heater efficiency is assumed to be 100%.

Equation 5-8. Total energy consumption (TEC) calculation (only applies to high temperature devices)

$$Electric_n = WaterE_n + Idle_n$$

where

$Electric_n$ = Total electric consumption per year in year *n* (kWh/yr)
$WaterE_n$ = Booster heater unit energy consumption in year *n* (kWh/yr)
$Idle_n$ = Idle energy per year in year *n* (kWh/yr)

Our REF UEC is calculated as follows for gas.

Equation 5-9. Total gas consumption calculation

$$Gas_{REFn} = (Water_{REFn} * DWater * SHWater * Degrees) / Eff \ /10\text{^}6$$

where

Gas_{REFn} = Reference unit energy consumption in year *n* (MBtu/yr)
$Water_{REFn}$ = Reference water use in year *n* (gal/yr)
DWater = Density of water (lb/gal)
SHWater = Specific heat of water (Btu/lb-degree Fahrenheit)
Degrees = Temperature rise in main tanks (Fahrenheit)
Eff = Efficiency of gas water heater (%)

Total energy consumption and savings for any dishwasher type include both the electric and gas components. The difference between our REF and Energy Star UEC is due to differences in the gallon per rack and idle rate inputs.

<u>Decorative Light Strand and Light Fixture</u>

The calculation is based on lamps per device and watts per lamp. Our UEC is calculated as follows:

Equation 5-10. Lighting unit energy consumption calculation

$$UEC_n = (On_n * HY * numlamps) / 1000$$

where

UEC_n = The unit energy consumption in year *n* (kWh/yr)
On_n = On mode power per lamp in year *n* (W)
HY = Hours per year (hrs/yr)
numlamps = Number of lamps per fixture

The difference between our REF and Energy Star UEC is due to the difference in *on* power per lamp.

Dehumidifier

The calculation is based on the energy factor and capacity of the unit. Our UEC is calculated as follows:

Equation 5-11. Dehumidifier unit energy consumption calculation

$$UEC_n = C * \mathrm{HY}/24/\mathrm{EF}_n$$

where

UEC_n = The unit energy consumption in year *n* (kWh/yr)
C = The unit capacity (pints/day)
HY = Hours per year (hrs/yr)
EF_n = The energy factor for year n (pints/kWh)

The difference between our REF and Energy Star UEC is due to the difference in the energy factor.

Exit Sign

The calculation is based on the wattage per sign and represents a technology market share weighted average of incandescent, CFL, and non-Energy Star light-emitting diode (LED) lamps. Our UEC is calculated as follows:

Equation 5-12. Exit sign unit energy consumption calculation

$$UEC_n = (IOn_n * IMS_n + CFLOn_n * CFLMS_n + LEDOn_n * LEDMS_n) / (IMS_n + CFLMS_n + LEDMS_n) * 8760/1000$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
IOn_n = Incandescent power in year *n* (W)
IMS_n = Incandescent market share in year *n* (%)
$CFLOn_n$ = CFL power in year *n* (W)
$CFLMS_n$ = CFL market share in year *n* (%)
$LEDOn_n$ = Non-qualifying LED power in year *n* (W)
$LEDMS_n$ = Non-qualifying LED market share in year *n* (%)

The difference between our REF and Energy Star UEC is due to the difference in power per sign. Energy Star assumes a 5 watt (W) criterion and 8,760 operation hours per year, regardless of technology.

Fryer and Steamer

The calculation includes cooking energy, idle energy, and preheat energy consumption. We include separate calculations for gas and electric units. Our detailed UEC calculation for electric units is presented as follows:

Equation 5-13. Daily cooking energy consumption calculation

$$CE_n = FD * EF / CE$$

where

CE_n = Cooking daily energy consumption in year *n* (kWh/day)
FD = Food cooked per day (lb/day)
EF = Energy required to cook food (kWh/lb)
CE = Business as usual cooking efficiency (%)

Equation 5-14. Daily idle time calculation

$$IT_n = HR - (FD / FR) - (PD * PT / 60)$$

where

IT_n = Idle time in year *n* (hrs/day)
HR = Daily hours of use (hrs/day)
FD = Food per day (lb/day)
FR = Cooking rate (lb/hr)
PD = Number of preheats per day
PT = Preheat time per preheat (min)

Equation 5-15. Idle electric consumption calculation

$$IE_n = IT_n * IR_n / 1000$$

where

IE_n = Idle energy in year *n* (kWh/day)
IT_n = Idle time in year *n* (hrs/day)
IR_n = Idle rate (W)

Equation 5-16. Total annual electric consumption

$$TE_n = (PE / 1000) + IE_n + CE_{REFn}$$

where

TE_n = Total annual energy in year *n* (kWh/yr)
PE = Reference preheat energy - given (kWh/day)
IE_n = Reference idle energy in year *n* (kWh/day)
CE_{REFn} = Reference annual cooking energy consumption in year *n* (kWh/day)

Hot Food Holding Cabinet (HFHC)

HFHC energy consumption is based on power per volume and the volume of the device. Our UEC is calculated as follows:

Equation 5-17. Annual energy consumption calculation

$$UEC_n = PV_n * Vol * HY / 1000$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
PV_n = Power per volume in year *n* (W/ft^3)
Vol = Interior volume of cabinet (ft^3)
HY = Annual hours of use (hr/yr)

The difference between our REF and Energy Star UEC is due to the difference in the power per volume input.

Ice Machine

The calculation is based on the annual ice harvest and the energy consumption per harvest. Our UEC is calculated as follows:

Equation 5-18. Annual energy consumption calculation

$$UEC_n = (ECR_n * HR * Use)$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
ECR_n = Energy consumption per harvest in year *n* (kWh/100 lbs ice)
HR = Harvest rate (100 lbs ice/day of operation)
Use = Days in use (operating days/yr)

The difference between our REF and Energy Star UEC is due to the difference in the energy consumption per harvest.

Refrigerated Beverage Vending Machine

The calculation is based on the daily energy requirements per machine. Our UEC is calculated as follows:

Equation 5-19. Annual energy consumption calculation

$$UEC_n = DEC_n * 365$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
DEC_n = Daily energy consumption (kWh/day)

The difference between our REF and Energy Star UEC is due to the difference in the daily energy consumption per unit. Our Energy Star UEC also addresses units with optional power management capability. The equations for calculating the Energy Star UEC are as follows.

Equation 5-20. Annual energy consumption calculation

$$UEC_{ES} = UEC_{Enabled} * Pct_{Enabled} + UEC_{NotEnabled} * (1 - Pct_{Enabled})$$

where

UEC_{ES} = Energy Star annual energy consumption for the capacity type in year *n* (kWh/yr)
$UEC_{Enabled}$ = Annual energy consumption for Energy Star enabled units in year *n* (kWh/yr)
$Pct_{Enabled}$ = Percentage of Energy Star units enabled in year *n* (%)
$UEC_{NotEnabled}$ = Annual energy consumption for not enabled Energy Star in year *n* (kWh/yr)

The not enabled UEC is the Energy Star criterion value, which is calculated as follows:

Equation 5-21. Energy Star Tier calculation

$$UEC_{T1} = (0.55 * 8.66 + 0.009 * C) * 365$$
$$UEC_{T2} = (0.45 * 8.66 + 0.009 * C) * 365$$

where

$UEC_{NotEnabled}$ = UEC_{T1} or UEC_{T2}, depending on year (kWh/yr)
UEC_{T1} = Energy Star Tier 1 criterion energy consumption for the capacity type in year *n* (kWh/yr)
UEC_{T2} = Energy Star Tier 2 criterion energy consumption for the capacity type in year *n* (kWh/yr)
C = machine capacity (cans/day)

For power-managed machines, a percentage of the machine load is calculated for each component: compressor, fan, lighting, and "other." The enabled UEC is then the sum of the component consumptions under the power-managed scenario.

Equation 5-22. Annual energy consumption calculation

$$UEC_{Enabled} = UEC_{compressor} + UEC_{fan} + UEC_{lighting} + UEC_{other}$$

where

$UEC_{Enabled}$ = total annual energy consumption in year *n* (kWh/yr)
$UEC_{compressor}$ = annual energy consumption of compressor in year *n* (kWh/yr)
UEC_{fan} = annual energy consumption of fan in year *n* (kWh/yr)
$UEC_{lighting}$ = annual energy consumption of lighting in year *n* (kWh/yr)
UEC_{other} = annual energy consumption of other components in year *n* (kWh/yr)

Room Air Cleaner

The calculation is based on the clean air delivery rate (CADR, measured as volume of air cleaned per minute or cubic meter per minute [m^3/min]) per watt. Our UEC is calculated as follows:

Equation 5-23. Annual energy consumption calculation

$$UEC_n = C_n * EF_n * 8760/1000$$

where

UEC_n = The unit energy consumption in year *n* (kWh/yr)
C_n = The unit capacity (CADR)
EF_n = The energy factor for year *n* (W/CADR)

The difference between our REF and the Energy Star UEC is due to the difference in the energy factor (W/CADR).

Traffic Signal

The calculation is based on the wattage per signal and the annual hours of use. Our UEC is calculated as follows:

Equation 5-24. Annual energy consumption calculation

$$UEC_n = (On_n * HY)/1000$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
On_n = *On* mode power per signal in year *n* (W)
HY = Hours per year (hrs/yr)

The difference between our REF and Energy Star UEC is due to the difference in power per signal.

Transformer

The calculation is based on the transformer rating, load factor, and unit efficiency of the device. Our UEC is calculated as follows:

Equation 5-25. Annual energy consumption calculation

$$UEC_n = R * (1 - Eff_n) * LF * LM * 8760 hrs / yr$$

where

UEC_n = Annual energy consumption in year *n* (kWh/yr)
R = Transformer rated power (kW)
Eff_n = Unit efficiency in year *n* (%)
LF = Load factor (%)
LM = Loss multiplier (1.1)

The difference between our REF and Energy Star UEC is due to the difference in the transformer efficiency.

5.3. General Equations for Calculating Energy Star Unit Savings (UES)

Once the REF and Energy Star UECs are calculated, a UES is established by subtracting the Energy Star UEC from the non-Energy Star UEC.

Equation 5-26. Calculate Energy Star UES

$$UES_n = UEC_{NES_n} - UEC_{ES_n}$$

where

UES_n = annual unit energy savings in year *n* (kWh/yr)
UEC_{NES} = Non-Energy Star unit energy consumption in year *n* (kWh/yr)
UEC_{ES} = Energy Star unit energy consumption in year *n* (kWh/yr)

In the majority of cases, the non-Energy Star UEC is equivalent to the REF UEC, Equation 5-27. However, there are cases where our reference case penetration exceeds program participation (free riders), and we calculate our non-Energy Star UEC by modeling an increasing market share

of high-efficiency (non-Energy Star) units Equation 5-28. The two equations that summarize these calculations are as follows:

Equation 5-27. Setting non-Energy Star UEC to equal REF UEC

$$UEC_{NES_n} = UEC_{REF_n}$$

where

UEC_{NESn} = Non-Energy Star unit energy consumption in year *n* (kWh/yr)
UEC_{REFn} = REF unit energy consumption in year *n* (kWh/yr)

Equation 5-28. Calculate non-Energy Star UEC

$$UEC_{NES_n} = (UEC_{REF_n} * (X_n - RC_n) + UEC_{ES_n} * (RC_n - FR_n)) / (X_n - FR_n)$$

where

UEC_{NESn} = Non-Energy Star annual energy consumption in year *n*
UEC_{REFn} = REF annual energy consumption in year *n*
RC_n = U.S. sales of reference case units in year *n*
X_n = U.S. sales of product in year *n*
UEC_{ESn} = Energy Star annual energy consumption in year *n*
FR_n = U.S. sales of free rider units in year *n*

5.4. General Equations for Calculating Energy Star Annual Savings (AES)

For all years where market transformation is not in effect, the UES and Energy Star labeled shipments attributed to program are used to calculate annual energy savings, annual energy bill savings, and annual carbon savings in a given year *t*, according to Equation 4-1 (Page 14).

For all years where market transformation is active, annual energy, energy bill, and carbon savings in a given year *t* are calculated according to Equation 4-2 (Page 15).

Details regarding Energy Star shipments, Energy Star shipments due to program, and detailed inputs can be found in Section 6.

Table 5-4 lists the relevant approach for each product included in this analysis.

Table 5-4. Non-Energy Star calculation approach by product

Product	Equation 5-27	Equation 5-28
Computer	X	
Monitor	X	
Fax	X	
Copier	X	
Multifunction Device	X	
Scanner	X	
Printer	X	
TV	X	
VCR	X	
TV/VCR/DVD	X	
DVD Player	X	
Audio Equipment	X	
Telephony		X
Digital TV Adapter	X	
Set-top Box	X	
External Power Supply		X
Battery Charging System		X
Furnace (Gas or Oil)	X	
Central Air Conditioner	X	
Air-Source Heat Pump	X	
Geothermal Heat Pump		X
Boiler (Gas or Oil)	X	
Programmable Thermostat		X
Light commercial HVAC	X	
Fixture		X
Exit Sign		X
Decorative Light Strand		X
Traffic Signal	X	
Dehumidifier		X
Air Cleaner		X
Exhaust Fan		X
Ceiling Fan	X	
Water Cooler	X	
Commercial Refrigeration	X	
Hot Food Holding Cabinet	X	
Fryer	X	
Steamer	X	
Ice Machine		X
Commercial Dishwasher		X
Vending Machine	X	
Utility Transformer	X	
C&I Transformer	X	
Residential Roofing	X	
Commercial Roofing	X	

6. Product Category Methodologies

This section presents relevant methodological information by product category. Product categories were defined by grouping products with similar methodologies. Each product category methodology consists of a description of the category and the current Energy Star performance criteria. The performance criteria are included to demonstrate the applicability of our product approach toward evaluating energy savings.

Within each product category, a description is presented for each included product. Each product description includes three components: U.S. sales, key baseline assumptions, and modeling data. These data are key to evaluating Energy Star results and uncertainty. We present these data to demonstrate estimated versus reported unit sales, estimated versus measured input data, and our reliance on current sources, as well as baseline assumption sources and relevance.

Table 6-1 shows an overview of the modeling approach for seven top-level product categories.

Table 6-1. Modeling approach for top-level (aggregated) product categories

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Office equipment	Energy Star specification supplemented by field and laboratory power consumption test data and field survey operating patterns	Industry literature. Confirmed with EIA model	Market/ industry reports	Monitors – reported by manufacturers All other equipment – market research	Monitors, desktops, fax, scanners, printers, MFDs: no PM in baseline all shipments due to program Exceptions: notebooks, inkjet fax, inkjet printer, inkjet MFD assume 0% due to program until 2007 spec change, 50% onward Copiers, PM in baseline, all shipments due to Energy Star Notebooks, PM in baseline	Savings incorporate power management success rates based on field operating pattern surveys; power management rates dominate energy savings estimates Computer and inkjet imaging products hours of use and power consumption updated in 2007 (analysis year 2006). Monitors hours of use updated in 2007 (analysis year 2006) Inputs coordinated with EIA model. Inkjet imaging and notebook baseline UECs account for EPS savings

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Office equipment (cont'd)					Notebooks and inkjet imaging: baseline UEC drops in 2005 and 2009 due to EPS program and federal standard Baseline UECs reflect increasing active power consumption LCD and inkjet consumption reduced in 2005/2009 to account for EPS E* and fed standard	
Consumer electronics	Energy Star specification supplemented by field and laboratory power consumption test data and field and/or phone survey operating patterns	Industry literature	Market/ industry reports	Reported by manufacturers	Baseline penetration varies by product category determined as a percentage of product models on the market at time of spec development that met criteria based on independent field power consumption measurements	Power consumption and usage patterns for all product categories updated in 2007 (analysis year 2006). Inputs coordinated with EIA model.

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Consumer electronics (continued)					Products with declining baseline standby power: projection and plasma TVs, DVDs, mini-systems, home theatres Telephony, LCD TV, CD baseline consumption reduced in 2005 and 2009 to account for EPS program impact and EPS federal standard	
Lighting	Fixture power consumption based on field monitoring and usage patterns from refereed literature All others: engineering estimates from published sources	Based on ballast lifetime (industry product specs) and operating time	Market/ industry reports	Reported by manufacturers	Fixtures: increasing baseline penetration Exit signs: dramatically increasing baseline penetration (94% in 2005) Traffic signals: increasing baseline penetration	Updated in 2007 (analysis year 2006) to reflect current literature/field measurement studies In 2006, the federal standard for traffic signals and exit signs is effective and no savings from new sales accrue beginning in 2006

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Lighting (continued)					DLS: increasing baseline penetration Baseline penetrations are from utility field surveys of qualifying technologies and forecasted market adoption rates Baseline UECs for fixtures held constant Baseline UECs for traffic signals set to federal standard in 2006 Baseline UEC for exit signs set to federal standard in 2006	

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
HVAC	Modeled using household characteristics from RECs and NAECA vs. Energy Star efficiency requirements	Industry literature	Market/ industry reports	Reported by manufacturers	Baseline UEC assumes federal minimum efficiency criteria Baseline penetrations taken from historic industry/trade breakdowns of product market by efficiency (AFUE, SEER) Light commercial HVAC baseline UEC set to federal standard in 2010	Energy Star HVAC sales are first credited to the Energy Star Homes program. Remaining sales attributable to Energy Star are then allocated to product labeling. Program double counting is avoided
Programmable thermostat	Industry energy savings calculator	Assumed replaced when HVAC replaced	Industry estimates	Industry literature	Baseline penetration increases from 20% in 1995 to 38% in 2007. Baseline penetration from industry projections. Baseline UEC declines due to changed federal standards and installation of Energy Star HVAC equipment	Savings incorporate an enabling rate Only accrue savings for heating Thermostat specification is to be sun set and no savings accrue after 2010

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit Energy Savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Residential appliances	Field and laboratory energy/power consumption test data, operating times from industry literature	Industry literature	Market/ industry reports	Reported by manufacturers	Baseline penetration varies by product category determined as a percentage of product models on the market at time of spec development that met criteria based on independent energy consumption measurements Baseline penetration for air cleaners held constant. Ceiling fan and ventilation fan baseline penetration increases over time. Baseline UECs for ceiling fan, lighting, and dehumidifiers decline due to federal standard Baseline UECs for air cleaners, ventilation fans constant.	U.S. EPA administered products only

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit energy savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Commercial Appliances	Field and laboratory test data of the Food Service Technology Center	Food Service Technology Center	Industry reports	Reported by manufacturers	Vending: baseline penetration declines due to Tier 2 requirements Water coolers: 0% baseline penetration Other products: baseline penetration increases over time Baseline UECs: held constant over time	Commercial refrigerators/freezers and vending energy consumption estimates confirmed with EIA model. Inputs for hot food holding cabinets, steamers, and fryers updated in 2008. Low program participation versus baseline penetration
External Power Supply	Modeled from specific product analyses and PS efficiency	Based on specific product analyses	Market/ industry reports	Reported by manufacturers	Baseline penetrations based on specific product analyses UECs decline due to Federal Standard	EPS savings credited to this specification, baseline for end use products (TVs, telephones, etc) have improvements modeled in their baseline to avoid double counting

Table 6-1. (continued)

	Key Parameters					
Product Categories	**Unit energy savings**	**Lifetime**	**Total Product Shipments**	**Annual Energy Star shipments**	**Baseline Energy Star shipments**	**Notes**
Battery Charging System	Energy Star specification supplemented by field and lab power consumption test data and field survey operating patterns	Industry literature	Market/ industry reports	Reported by manufacturers	Baseline UECs: held constant over time 0% baseline penetration	
Others	Energy Star specification and in field test measurements Roofing: Energy Star UES taken directly from technical report.	Transformers: Industry report and estimates Roofing: National Roofing Contractors Association and manufacturer data	Transformers: industry reports and estimates Roofing: National Roofing Contractors Association and manufacturer data	Transformers: industry reports and estimates Roofing: National Roofing Contractors Association and manufacturer data	Utility transformer baseline UEC 10% in 1995 and held constant to 2005 Roofing: prior to Energy Star, 5% of all roofing sold estimated to be reflective. 20% assumed sold to residential sector. Free rider market penetration is set to 0.05% of all sales based on estimates of Energy Star unit sales during the early years of the program.	Utility transformers suspended in 2002, C&I transformers suspended in 2007, transformer specification terminated in 2007. Energy Star's new home program gets first claim on all sales above free rider level and Energy Star is attributed whatever sales remain.

6.1. Audio and Visual (AV)

Product Category Description

Energy Star AV includes video cassette recorders (VCRs), digital versatile discs (DVDs), compact mini-systems, home theater-in-a-box (HTIB), audio separates, and compact discs (CD). Energy Star AV was launched in 1999, with the exception of VCRs, which was launched in 1998.

Energy Star Performance Criteria

Energy Star-qualified AV are required to meet a one-watt *standby* mode criteria.

VCR

The VCR product category covers VCRs and VCR/DVD combination units.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (*Appliance Magazine* 2000, 2003, 2007, CEA 2005). Energy Star unit sales (1999–2007) are manufacturer-reported sales of Energy Star units (CEA 2000, 2001, 2003; ICF 2004, 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

The reference case market penetration is based on manufacturer test data submitted to U.S. EPA in 1999 and is set to 0% (held constant over time). The free rider market penetration is also set to 0%. We also account for the following REF trends:

- Decreasing *active* mode power from 18 W in 1999 to 12 W in 2007
- Decreasing *on* mode power from 11 W in 1999 to 7 W in 2007
- Declining hours of use based on product obsolescence

Modeling Data for Calculating Energy Star Savings

We calculate separate UECs for VCR and VCR/DVD combination units and create a sales-weighted average UEC to quantify program impacts for the VCR product category.
REF *active* and *standby* power is measured data from Roth and McKenney (2007). REF *on* power is field-measured data from Porter et al. (2006). Energy Star *active* and *on* mode power is equal to REF minus improvements that had been made to reduce standby consumption that carry over into *on* mode power reductions. Energy Star standby power used in the analysis represents wattage levels achieved under each specification, as reported by manufacturers to U.S. EPA (approximately 10% below the specification), which is equivalent to 0.9 W. We assume an annual usage of 351 days per year in which usage continually declines from 3 hours per day in *active* mode and 3 hours per day in *on* mode (1999) to 0.7 hours per day in *active* mode and 1.5

hours per day in *on* mode (2007). Usage patterns are based on measured duty cycles from Porter et al. (2006).

Table 6-2. UEC inputs for VCRs in 2007

VCR Performance	REF	Energy Star
Active (W)	12	9
On (W)	7	4
Standby (W)	4	1
Active (hrs/day)	1	1
On (hrs/day)	2	2
Standby (hrs/day)	22	22
% Units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	38	11

Note: Hours may not sum to 24 due to rounding.

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

DVD

The DVD product category covers DVDs and DVD recorders.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (*Appliance Magazine* 2006; CEA 2003, 2005). Energy Star unit sales (2003–2007) are manufacturer-reported sales of Energy Star units (CEA 2003; ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

The reference case market penetration is set to 33% through 2002 and then to 0% to reflect the current one-watt criterion that becomes effective in 2003. The reference case penetration is based on LBNL metering data collected circa 1998 (Floyd and Webber 1998). The free rider market penetration is also set to 33%. We also account for the following REF trends:

- Decreasing *standby* mode power from 6 W in 1999 to 3 W in 2007 (Roth and McKenney 2007.

Modeling Data for Calculating Energy Star Savings

We calculate separate UECs for DVD and DVD recorders and create a sales weighted average UEC to quantify program impacts for the DVD product category. REF *active* power is measured data from Floyd and Webber (1998) and Roth and McKenney (2007). REF *on* power is measured data from Porter et al. (2006). REF standby power is measured data from Floyd and Webber

(1998). Energy Star *active* and *on* mode power is equal to REF minus improvements that had been made to reduce standby consumption that carry over into *on* mode power reductions. Energy Star standby power used in the analysis represents wattage levels achieved as found in Roth and McKenney (2007), which is equivalent to 0.5 W. We also account for savings in *active* and *on* mode that resulted from improvements made to reduce standby power consumption. We assume an annual usage of 351 days per year in which usage increases from 3 hours per day in *active* mode in 1999 to 5 hours per day in *active* mode in 2007. Usage patterns are measured duty cycles from Porter et al. (2006).

Table 6-3. UEC Inputs to DVD in 2007

DVD Performance	REF	Energy Star
Active (W)	16	14
On (W)	9	7
Standby (W)	3	1
Active (hrs/day)	5	5
On (hrs/day)	0	0
Standby (hrs/day)	19	19
% Units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	44	26

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26. and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

Mini-System

The mini-systems product category covers compact audio systems.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (*Appliance Magazine* 2006, 2007a, 2007b; CEA 2003, 2005). Energy Star unit sales (2003–2007) are manufacturer-reported sales of Energy Star units (CEA 2003, 2005; ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

The reference case market penetration is set to 2% through 2002 and then to 0% when the current one-watt criterion becomes effective (2003). It is based on field measurements of audio equipment (Webber 1999). The free rider market penetration is also set to 2% and 0%. We also account for the following REF trend:

- Decreasing *standby* mode power from 10 W in 1999 to 5 W in 2007 (Roth and McKenney 2007)

Modeling Data for Calculating Energy Star Savings

Active, *on*, and *standby* mode power consumption are measured data from Roth and McKenney (2007). Energy Star standby power used in the analysis represents wattage levels achieved as found in Roth and McKenney 2007, which is equivalent to 0.6 W. We do not account for savings in *active* and *on* mode that might have resulted from improvements made to reduce standby power consumption, since measured data published in Roth and McKenney 2007 showed no such effect. We assume an annual usage of 351 days per year, in which usage is equivalent to 2 hours per day in *active* mode and 2 hours per day in *on* mode held constant over time. Usage patterns are based on a household phone survey (Roth and McKenney 2007).

Table 6-4. UEC inputs to mini-systems in 2007

Mini-System Performance	REF	Energy Star
Active (W)	23	23
On (W)	16	16
Standby (W)	5	1
Active (hrs/day)	2	2
On (hrs/day)	2	2
Standby (hrs/day)	20	20
% Units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	66	34

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26. and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

Home Theater in a Box (HTIB)

The HTIB product category covers audio equipment sold as a system (with one manufacturer model number) including a receiver subwoofer and DVD player.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (*Appliance Magazine* 2006, 2007a, 2007b; CEA 2006). Energy Star unit sales are manufacturer-reported sales of Energy Star units (2003–2006) (CEA 2003, 2005; ICF 2007).

Key Baseline Assumptions

The reference case market penetration is an LBNL estimate set to 0%, and there are no free riders. We account for the following REF trends:

- Decreasing *active* mode power from 46 W in 1999 to 40 W in 2007 (Roth and McKenney 2007)

- Decreasing *on* mode power from 42 W in 1999 to 38 W in 2007 (Roth and McKenney 2007)
- Decreasing *standby* mode power from 3 W in 1999 to 2 W in 2007 (Roth and McKenney 2007)

Modeling Data for Calculating Energy Star Savings

Active, on, and *standby* mode power consumption are measured data from Roth and McKenney (2007). Energy Star standby power used in the analysis represents wattage levels achieved as found in Roth and McKenney 2007, which is equivalent to 0.6 W. We also account for savings in *active* and *on* mode that resulted from improvements made to reduce standby power consumption. We assume an annual usage of 351 days per year in which usage is equivalent to 4 hours per day in *active* mode and 2 hours per day in *on* mode held constant over time. Usage patterns are based on a household phone survey (Roth and McKenney 2007).

Table 6-5. UEC inputs to HTIB in 2007

HTIB Performance	REF	Energy Star
Active (W)	40	38
On (W)	38	36
Standby (W)	2	1
Active (hrs/day)	4	4
On (hrs/day)	2	2
Standby (hrs/day)	18	18
% Units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	103	87

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26. and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Audio Separates

The audio separates product category covers mini discs, receivers, amplifiers, and speakers. We track UECs separately, although results are calculated as a sales weighted average of the individual audio components.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (CEA 2003, 2005). Energy Star unit sales (2003–2007) are manufacturer-reported sales of Energy Star units (CEA 2003, 2005; ICF 2007, 2008).

Key Baseline Assumptions

The reference case market penetration is an LBNL estimate set to 0%, and there are no free riders. Our REF is held constant over time. The REF UEC reflects three power-consuming modes: *active, on,* and *standby. Active, on,* and *standby* mode power consumption are measured data from Webber (1999). Usage assumptions are LBNL estimates also from Webber (1999). Applicable UECs used in this analysis for each audio component type are listed below. We assume that audio separates are used 365 days per year.

Table 6-6. Summary of audio separates UECs in 2007

Audio Separates Performance	REF (kWh/yr)	Energy Star (kWh/yr)	Weighting (%)
Mini Disc	44	10	9
Receiver	53	45	83
Amplifier	56	46	1
Speakers	48	8	6
Weighted Average Audio Separates	52	39	

The UES is calculated according to Equation 5-26. and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

CD

The CD product category covers stand-alone CD players.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (CEA 2003, 2005). Energy Star unit sales (2004–2007) are manufacturer-reported sales of Energy Star units (ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

Reference case is 18% through 2002 and then 0%. Our REF accounts for efficiency improvements in external power supplies due to the federal minimum energy standard and the Energy Star power supplies specification.

Modeling Data for Calculating Energy Star Savings

REF *active, on,* and *standby* mode power consumption are measured data from Floyd and Webber (1998). Energy Star standby power used in the analysis represents wattage levels achieved under each specification as reported by manufacturers to U.S. EPA (approximately 10% below the specification), which is equivalent to 0.9 W. We also account for savings in *active* and *on* mode that resulted from improvements made to reduce standby power consumption. We assume an annual usage of 351 days per year in which usage is equivalent to

0.24 hours per day in *active* mode and 23.76 hours per day in standby mode held constant over time (Porter et al. 2006). Usage patterns are based on measured duty cycles.

Table 6-7. UEC inputs to CDs in 2007

CD Player Performance	REF	Energy Star
Active (W)	8	6
On (W)	7	4
Standby (W)	4	1
Active (hrs/day)	0	0
On (hrs/day)	0	0
Standby (hrs/day)	24	24
% Units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	31	8

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26. and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

6.2. Commercial Cooking

Product Category Description

Commercial cooking equipment includes hot food holding cabinets (HFHC), steamers, and fryers. The commercial cooking equipment module started in 2003.

Energy Star Performance Criteria

HFHC must meet a maximum idle energy rate of 40 watts per cubic foot (W/ft^3).

Steamer and fryer must meet the requirements in Table 6-8 and Table 6-9.

Table 6-8. Energy Star steamer performance requirements

Energy Efficiency Requirements for Steam Cookers				
Pan Capacity	Electric		Gas	
	Cooking Energy Efficiency (%)	Idle Rate (watts)	Cooking Energy Efficiency (%)	Idle Rate (Btu/h)
3-pan	50	400	38	6,250
4-pan	50	530	38	8,350
5-pan	50	670	38	10,400
6-pan and larger	50	800	38	12,500

Source: U.S. EPA (2003a)
Note: Cooking efficiency based on heavy load.

Table 6-9. Energy Star fryer performance requirements

Energy Efficiency Requirements for Fryers		
	Electric	**Gas**
Heavy Load (French fry) Cooking Energy Efficiency	> 80%	> 50%
Idle Energy Rate	< 1000 watts	< 9,000 Btu/h

Source: U.S. EPA (2003b).
Note: Based on a 15″ fryer.

Hot Foods Holding Cabinet (HFHC)

The U.S. EPA defines an HFHC as an appliance that is designed to hold hot food that has been cooked using a separate appliance at a specified temperature. These appliances are divided into three categories: full-size, three-quarter size, and half-size units. These product categories are differentiated by the interior volume of cabinet space: 20 ft^3, 15 ft^3, and 10 ft^3, respectively.

U.S. Sales

U.S. sales data for 2003 are from the North American Association of Food Equipment Manufacturers (NAFEM) report, *Size and Shape of the Industry Study: Storage and Handling Equipment* (NAFEM 2004a). From 2004 to 2025, HFHC sales are expected to increase at an annual rate of 1.5%, which is equivalent to the growth in commercial floor space over the same period (U.S. DOE 2003a). Energy Star sales from 2004–2007 are manufacturer-reported sales (ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

According to the Food Service Technology Center (FSTC), approximately 35% of full-size models were able to meet the Energy Star HFHC specification in 2003, based on manufacturer test data (Zabroski 2003). Forty percent of three-quarter and half-size models were able to meet the Energy Star specification in 2003. Actual sales data show that despite the high market share of units that were able to meet the performance requirement, a relatively low market share of units actually participate in the program (7% in 2003 and 17% in 2007). To account for this, we set the reference case and free rider reference case penetration equal to annual Energy Star market share and increase the percentage until it is above the 35%/40% threshold. As a result, HFHCs do not accrue any savings through 2007, since we estimate that all Energy Star sales are not due to the Energy Star program. Our REF UEC is held constant over time.

Modeling Data for Calculating Energy Star Savings

Inputs to our REF UEC are engineering data taken from the FSTC (Zabroski 2008). Our duty cycle assumes 15 hours per day of use, 365 days per year. Our REF assumptions are shown in Table 6-10**.**

Table 6-10. REF Assumptions for HFHC in 2007

Class	Volume (ft^3)	Energy Consumed (watts/ft^3)
Full Size	20	125
¾ Size	15	100
½ Size	10	100

Source: Zabroski (2008).

Our Energy Star UEC assumes the same duty cycle and volume as the REF case, with the exception that qualifying units meet a 40 W/ft^3 requirement.

The REF and Energy Star UECs are calculated according to Equation 5-17. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Commercial Steamer in 2007

The U.S. EPA defines a commercial steam cooker as a device with one or more food steaming compartments in which the energy in the steam is transferred to the food by direct contact. Steamers are divided into two categories: electric steamers and gas steamers.

U.S. Sales

U.S. sales data for 2003 are from the NAFEM report, *Size and Shape of the Industry Study: Primary Cooking Equipment* (NAFEM 2004b). The breakdown of sales between gas and electric markets is from email communication with ICF Consulting in August 2005 (Duff 2005). From 2004 to 2025, steamer sales are expected to increase at an annual rate of 1.5%, which is equivalent to the growth in commercial floor space over the same period (U.S. DOE 2003a). Energy Star sales from 2004–2007 are manufacturer-reported sales (ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

According to the FSTC, approximately 30% of electric steamers and 5% of gas steamers were able to meet the Energy Star specification prior to the program launch, based on manufacturer test data. Actual sales data show that despite the high market share of units that were able to meet the performance requirement, a relatively small volume of electric steamers actually participate in the program (11% in 2003 and 15% in 2007). To account for this, we set the reference case and free rider reference case penetration equal to the actual Energy Star market share and increase the percentage until it is above the 30% threshold. As a result, electric steamers have not accrued any savings through 2007, since we estimate that all Energy Star sales are not due to the program and not attributable to U.S. EPA (Zabroski 2003).

The gas steamer Energy Star market share is effectively 0%.

Modeling Data for Calculating Energy Star Savings

Inputs to our steamer UEC are engineering data taken from FSTC (Zabroski 2008). We calculate a separate UEC for gas and electric fuel types. Steamer calculations are based on a 3-pan unit. Table 6-11 and and Table 6-12 summarize key UEC inputs (taken directly from Zabroski 2008).

The REF and Energy Star UECs are calculated by Equation 5-13 through Equation 5-16. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Table 6-11. Detailed inputs for the electric steamer UEC in 2007

Category	Units	Value		Calculated value
		Energy Star	Conventional	
Cooking Energy Efficiency	%	50%[1]	26%	
Cooking Energy	kWh	6.2	11.8	y
Production Capacity				
Selected Pan Size	lb/hour	50	70	
Idle Energy Rate	watts	424	1,160	
Idle Energy Rate Multiplier		1.06	1.16	
Selected Pan Size	watts	400	1,000	
Total Idle Time	hour	9.75	10.32	y
Idle Energy	kWh	4.1	12.0	y
Energy to Food	Btu/lb	105	105	
Heavy Load	lb	3	3	
Preheat Energy	Wh/day	1,500	1,500	
Preheat Time	minutes	15	15	
Total Energy	kWh	11.8	25	y
Usage				
Avg number of operating hours per day	hrs/day	12	12	
Avg number of operating hours per year	hrs/year	4,380	4,380	y
Number of Days of operation	days/year	365	365	
Number of Preheats per day	preheat/day	1	1	
Pounds of Food Cooked per day				
Selected Pan Size	lb/day	100	100	

Source: U.S. EPA (2003) specification; all other values from Zabrowski (2008) unless marked as calculated.

Table 6-12. Detailed inputs for the gas steamer UEC in 2007

Category	Units	Value		Calculated value
		Energy Star	Conventional	
Cooking Energy Efficiency	%	38%[1]	15%	
Cooking Energy	Btu/day	27,632	70,000	y
Production capacity				
Selected pan size	lb/hour	120	140	
Idle Energy Rate	Btu/h	12,500[1]	16,000	
Idle Energy Rate Multiplier		1.06	1.16	
Selected pan size	Btu/h	12,500[1]	16,000	
Total Idle Time	hour	10.9	11.0	y
Idle Energy	Btu/day	136,458	176,571	y
Energy to Food	Btu/lb	105	105	
Heavy Load	lb	3	3	
Preheat Energy	Btu/day	9,000	18,000	
Preheat Time	minutes	15	15	
Total Energy	Btu/day	173,090	264,571	y
Usage				
Avg number of operating hours per day	hrs/day	12	12	
Avg number of operating hours per year	hrs/year	4,380	4,380	y
Number of Days of operation	days/year	365	365	
Number of Preheats per day	preheat/day	1	1	
Pounds of Food Cooked per day				
Selected pan size	lb/day	100	100	

Source: U.S. EPA (2003) specification; all other values from Zabrowski (2008) unless marked as calculated.

Fryer

A fryer is an appliance, including a cooking vessel, in which oil is placed to such a depth that the cooking food is essentially supported by displacement of the cooking fluid rather than by the bottom of the vessel. Heat is delivered to the cooking fluid by means of an immersed electric element or band-wrapped vessel (electric fryers), or by heat transfer from gas burners through either the walls of the fryer or through tubes passing through the cooking fluid (gas fryers).

U.S. Sales

U.S. sales data for 2003 are from the NAFEM report, *Size and Shape of the Industry Study: Primary Cooking Equipment* (NAFEM 2004b). From 2004 to 2025, fryer sales are expected to increase at an annual rate of 1.5%; equivalent to the growth in commercial floor space over the same period (U.S. DOE 2003a). Energy Star sales from 2004–2007 are manufacturer-reported sales (ICF 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

According to the FSTC, approximately 5% of electric fryers and 30% of gas fryers in 2003 were able to meet the Energy Star specification prior to the program launch, based on manufacturer data. The free rider penetration for electric fryers is also set at 5%. Actual sales data for gas

fryers show that despite the high market share of units that were able to meet the performance requirement, a relatively low market share of units actually participated in the program (1% in 2003 and 5% in 2007). To account for this, we set the reference case and free rider reference case penetration equal to Energy Star sales and increased the percentage until it is above the 30% threshold. As a result, gas fryers have not accrued any savings through 2007, since we estimated that all Energy Star sales are not due to the Energy Star program.

Modeling Data for Calculating Energy Star Savings

Inputs to our REF and Energy Star UECs are engineering data taken from FSTC (Zabrowski 2008). We calculated a separate UEC for gas and electric fuel types. Table 6-13 and Table 6-14 summarize the key inputs that went into our fryer UEC (taken directly from Zabrowski 2008).

The REF and Energy Star UECs are calculated by Equation 5-13 through Equation 5-16. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Table 6-13. Detailed inputs for the electric fryer UEC in 2007

Category	Units	Value		Calculated value
		Energy Star	Conventional	
Cooking Energy Efficiency	%	80%[1]	75%	
Cooking Energy	Wh	31,314	33,402	y
Production Capacity	lb/hour	70	65	
Idle Energy Rate	watts	1,000[1]	1,050	
Total Idle Time	hour	13.607	13	y
Idle Energy	watts	13,607	14,114	y
Energy to Food	Wh/lb	167	167	
Food Load	lb/day	150	150	
Heavy Load	lb	3	3	
Preheat Energy	Wh/day	1,700	2,300	
Preheat Time	minutes	15	15	
Total Energy	kWh	46.62	49.82	y
Usage				
Avg number of operating hours per day	hrs/day	16	16	
Avg number of operating hours per year	hrs/year	5,840	5,840	y
Number of days of operation	days/year	365	365	
Number of preheats per day	preheat/day	1	1	
Pounds of food cooked per day		150	150	

Source: U.S. EPA (2003) specification; all other values from Zabrowski (2008) unless marked as calculated.

Table 6-14. Detailed inputs for the gas fryer UEC in 2007

Category	Units	Value		Calculated value
		Energy Star	Conventional	
Cooking Energy Efficiency	%	50%[1]	35%	
Cooking Energy	Btu	171,000	244,286	y
Production capacity	lb/hour	65	60	
Idle Energy Rate	Btu/h	9,000[1]	14,000	
Total Idle Time	hour	13.44	13.25	y
Idle Energy	Btu	120,981	185,500	y
Energy to Food	Btu/lb	570	570	
Heavy Load	Btu	3	3	
Preheat Energy	minutes	15,500	16,000	
Preheat Time	Btu/day	15	15	
Total Energy	Btu	307,481	445,786	y
Usage				
Avg number of operating hours per day	hrs/day	16	16	
Avg number of operating hours per year	hrs/year	5,840	5,840	y
Number of days of operation	days/year	365	365	
Number of preheats per day	preheat/day	1	1	
Pounds of food cooked per day		150	150	

Source: U.S. EPA (2003) Specification; all other values from Zabrowski (2008) unless marked as calculated.

6.3. Commercial Dishwasher

Product Category Description

We analyze four types of commercial dishwashers: under counter, stationary rack/door, single tank conveyor, and multiple tank conveyor. The commercial dishwasher module begins in 2008.

For each dishwasher type, we analyze low-temperature (chemical sanitizing) and high-temperature (hot water sanitizing with booster heater) units separately, due to the presence of a booster heater in high-temperature units. We also analyze gas and electric energy consumption/savings separately. Gas savings accrue due to lowered water consumption in the main water heating tank (we assume a gas water heater). Electric savings accrue due to lowered idle electric consumption and lowered water consumption in the booster heating tank.

Energy Star Performance Criteria

Energy Star-qualified units must meet minimum idle rate performance criteria and water consumption criteria specified as gallons per rack. Energy Star criteria are listed in Table 6-17 below.

The U.S. EPA defines a commercial dishwasher as a machine designed to clean and sanitize plates, glasses, cups, bowls, utensils, and trays by applying sprays of detergent solution (with or without blasting media granules) and a sanitizing final rinse.

U.S. Sales

U.S. sales data for 2003 are from the NAFEM report *Size and Shape of the Industry Study: Warewashing Equipment* (NAFEM 2004c). From 2004 to 2025, dishwasher sales are expected to increase at an annual rate of 1.5%, which is equivalent to the growth in commercial floor space over the same period (U.S. DOE 2003a). All Energy Star sales are estimated by LBNL based on initial pass rates from manufacturer's test data collected during the product development process. Beginning in 2009, manufacturers will begin reporting Energy Star sales to U.S. EPA.

Key Baseline Assumptions

Reference case penetrations were calculated from the manufacturer's test data collected during product development. Our reference case penetration by dishwasher type is shown in Table 6-15**.**

Table 6-15. Summary of reference case penetrations for commercial dishwasher

	Low Temperature (%)	High Temperature (%)
Under the counter	46	47
Door	33	25
Conveyor	40	23
Multiple tank conveyor	41	24

Commercial food service equipment typically has Energy Star market penetrations that are substantially lower than the reference case market penetration. We assume this trend will continue for dishwashers, and we set the free rider market penetration to 10%. We will reevaluate this assumption when we receive manufacturer-reported Energy Star sales in 2010. Reference case and free rider market penetrations are held constant over time. Our REF UEC is held constant through time.

Modeling Data for Calculating Energy Star Savings

The following universal inputs are used in determining the UECs:

- Commercial gas water heater efficiency = 80%
- Temperature rise in main tank = 70°F
- Density of water = 8 lbs/gal
- Specific heat of water = 1 Btu/lb-degree Fahrenheit
- Booster heater efficiency = 100% (high temperature dishwashers only)
- Temperature rise in booster tank = 60°F (high temperature dishwashers only)

Table 6-16 shows inputs to the REF UEC calculation, and
Table 6-17 shows inputs used to determine the Energy Star UEC. REF inputs are based on manufacturer test data collected by U.S. EPA during specification development. Energy Star inputs are the maximum values allowable under the performance criteria.

Table 6-16. Inputs into REF UEC calculation in 2008 (specification start year)

Equip-ment	Racks/ day		Hrs/rack		Active (Hrs/day)		Standby (Hrs/day)		Idle Rate (kW)		Gallons/Rack (GPR)	
	L	H	L	H	L	H	L	H	L	H	L	H
Under-counter	300		0.035	0.039	10.5	11.7	13.5	12.3	0.154	0.418	1.95	1.98
Door	300		0.026	0.023	7.8	6.9	16.2	17.1	0.12	0.59	1.85	1.44
Con-veyor	600		0.005	0.005	3.06	2.9	20.9	21.1	0.69	2.05	1.23	1.13
Multi-tank con-veyor	600		0.004	0.003	2.52	2.1	21.5	21.9	1.6	2.42	0.99	1.1

Notes to Table 6-16:
- Data are taken from manufacturer test data assembled during product development.
- L = low-temperature machine; H = high-temperature machine

Table 6-17. Energy Star UEC inputs in 2008 (specification start year)

Equipment	Idle Rate (kW)		Gallons per Rack (GPR)	
	low temp	high temp	low temp	high temp
Under-counter	0.154	0.418	1.7	1.0
Door	0.12	0.585	1.18	0.95
Conveyor	0.69	2.00	0.79	0.70
Multi-tank conveyor	1.6	2.42	0.54	0.54

Note: These are maximum values allowable under the Energy Star specification.

The REF and Energy Star UECs are calculated according to Equation 5-5 through Equation 5-9. The UES is calculated according to Equation 5-26 and Equation 5-28. Energy Star program savings are calculated according to Equation 4-1.

6.4. Commercial Refrigeration

Product Category Description

Energy Star commercial refrigeration includes commercial ice makers, solid door commercial refrigerators and freezers, refrigerated beverage vending machines, and bottled water coolers. Energy Star commercial refrigeration was launched in 2000 with a specification for bottled water coolers. Solid door refrigerators and freezers were added in 2001, vending machines were added in 2004, and ice makers in 2008.

Energy Star Performance Criteria

Qualifying bottled water coolers, commercial refrigerators, freezers, and vending machines must meet limits on the maximum daily energy consumption. Ice makers must meet or exceed rates of energy (kWh/100 lbs ice produced) and potable water (gal/100 lbs ice produced) consumption. The requirements for commercial refrigeration products are summarized in Table 6-18.

Table 6-18. Energy Star performance requirements for commercial refrigeration

Category	Product Type	Requirements
Commercial Solid Door Refrigerator and Freezer		
	Refrigerators	< 0.10V + 2.04 kW-hrs/day
	Freezers	< 0.40V + 1.38 kW-hrs/day
	Refrigerator-Freezers	< 0.27AV - 0.71 kW-hrs/day
	Ice Cream Freezers	< 0.39V + 0.82 kW-hrs/day
Bottled Water Cooler		
	Cold only/cold and cook	< 0.16 kW hrs/day
	Hot and cold	< 1.20 kW hrs/day
Refrigerated Beverage Vending Machine		
	Tier 1	kWh/day: 0.55 [8.66 + (0.009 x C)]
	Tier 2	kWh/day: 0.45 [8.66 + (0.009 x C)]
Commercial Ice Maker		
	Ice Making Head (IMH) < 450 lbs/day	kWh/100 lbs ice: 9.23 – 0.0077H Water/100 lbs ice < 25 gal
	IMH > 450 lbs/day	kWh/100 lbs ice: 6.20 – 0.0010H Water/100 lbs ice < 25 gal
	Remote Condensing Unit (RCU) (integrated compressor) < 1000 lbs/day	kWh/100 lbs ice: 8.05 – 0.0035H Water/100 lbs ice < 25 gal
	RCU (integrated compressor) > 1000 lbs/day	kWh/100 lbs ice: 4.64 Water/100 lbs ice < 25 gal
	RCU (remote compressor) < 934 lbs/day	kWh/100 lbs ice: 8.05 – 0.0035H Water/100 lbs ice < 25 gal
	RCU (remote compressor) > 934 lbs/day	kWh/100 lbs ice: 4.82 Water/100 lbs ice < 25 gal
	Self-Contained Unit (SCU) < 175 lbs/day	kWh/100 lbs ice: 16.7 – 0.0436H Water/100 lbs ice < 35 gal
	SCU > 175 lbs/day	kWh/100 lbs ice: 9.11 Water/100 lbs ice < 35 gal

Notes to Table 6-18:
- V = Internal volume in ft^3
- AV = Adjusted volume = (1.63 x freezer volume) + refrigerator volume in ft^3
- C = vendible capacity
- H = Harvest rate, lbs ice / day

Bottled Water Cooler

A bottled water cooler is a freestanding device that consumes energy and dispenses water from removable plastic bottles. It is commonly positioned on top of the unit. There are two types of bottled water coolers: those that only provide cooling of the water and those that also dispense heated water.

U.S. Sales

U.S. sales estimates from 2000–2010 are from the Cadmus Group's market assessment (Cadmus Group 1999a). Years subsequent to 2010 are projected using a 1%/yr growth. Energy Star sales 2004–2007 are manufacturer sales as reported to U.S. EPA by its partners (ICF 2006a, 2006b, 2007, 2008). Other years are LBNL estimates.

Key Baseline Assumptions

The reference case penetration rate for high-efficiency units is 0%, based on measured data compiled by the Cadmus Group (Cadmus 2000a). Since the baseline penetration is 0%, there are also no free riders, and U.S. EPA is attributed savings for all Energy Star units. Both the reference case penetration and the REF UEC are held constant over time.

Modeling Data for Calculating Energy Star Savings

Bottled water cooler REF and Energy Star UEC represent annual standby consumption only. Our UECs are shown in Table 6-19. REF UEC is measured data from Cadmus (2000a), and Energy Star UEC is set to the maximum allowable under the specification.

Table 6-19. Bottled water cooler REF and Energy Star UEC in 2007

	REF (kWh/yr)	Energy Star (kWh/yr)
Cold only	106	58
Hot and cold	799	438

Source: Cadmus 1999b

The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Solid Door Commercial Refrigerator and Freezer

This product category covers commercial refrigerators, including reach-in, under counter, roll-in (or roll-through), and pass-through cabinets and solid door freezers.

U.S. Sales

2001 shipments are from the NAFEM report, *Size and Shape of the Industry Study: Refrigeration and Ice Machines* (NAFEM 2002). The report includes reach-in, pass-thru, under cabinet, and roll-thru refrigerators and solid door freezers. Future shipments are extrapolated based on the estimated growth 1997–2020 in electric refrigeration energy consumption from U.S. DOE (1999).

Key Baseline Assumptions

The initial (2001) commercial refrigerator reference case market penetration is set to 11% and rises to 32% in 2004, after which it is constant. The initial (2001) commercial freezer reference case market penetration is set to 17% and reaches 20% in 2003, after which is it constant (based on CEC 2001). The free rider market penetration for both products is set equal to the reference case market penetration. A new National Appliance Energy Conservation Act (NAECA) standard is scheduled for introduction in 2010. This standard will lower the average new unit

energy consumption to be equal to the Energy Star level. There are no savings attributed to U.S. EPA from that year forward.

Modeling Data for Calculating Energy Star Savings

Both the REF UECs are engineering data taken from (Wesphalen et al. 1996). The Energy Star UEC is set to the maximum energy consumption allowable under the specification. These machines are assumed to run constantly and do not have operational modes. UECs are shown in Table 6-20.

Table 6-20. REF and Energy Star UEC in 2007 and 2010 (New Federal Standard)

	REF 2007 (kWh/yr)	REF 2010 (kWh/yr)	Energy Star 2007 (kWh/yr)	Energy Star 2010 (kWh/yr)
Commercial refrigerator	4,300	2,332	2,332	2,332
Commercial freezer	5,200	3,818	3,818	3,818

Note: Data for 2007 and 2010 are displayed to show the impact of the federal minimum efficiency standard.

The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Refrigerated Beverage Vending Machine

This product category covers indoor, outdoor, and refurbished vending machines. Vending machines are classified in the analysis by capacity bins: 300-, 500-, 600-, 700-, and 800-can capacity. The Energy Star Tier 1 specification became effective in 2004; Tier 2 in 2007.

Unit Sales Data

Total U.S. sales data are estimated from shipment data and expected unit lifetimes. Shipment data is from market research by ICF Consulting and consultation with the National Automatic Merchandising Association (NAMA) (ICF 2002; Duff 2006). Energy Star sales 2004–2007 are manufacturer sales as reported to U.S. EPA by its partners (ICF 2006a, 2006b, 2007, 2008). Other years are LBNL estimates.

Key Baseline Assumptions

The reference case market penetration is different for each bin; the average is 30% in 2004, based on measured data from National Resources Defense Council (Horowitz 2004). With the introduction of the more stringent Tier 2 requirements, the reference case market penetration is set to 0% and remains constant. The free rider market penetration is also set to the reference case penetration.

Modeling Data for Calculating Energy Star Savings

The REF UEC is measured data from NRDC (Horowitz 2004). REF units do not have power management features, so no operational modes are modeled. Energy Star units have optional power management features that come into operation during periods of extended inactivity.

Power-managed machines are assumed to be typically inactive from 8 PM to 6 AM, to have a higher internal temperature during inactive times, amounting to 9% of the cooling energy based on NRDC testing (Horowitz 2004), and to have the lights dimmed during inactive time. Power management savings are calculated separately for the several components: compressor, fan, lighting and other functions. The savings for the compressor are reduced by 10% to account for the more complex start up/wake up cycles of power managed machines. Enabling rates are LBNL estimates, are set to 2% in 2004, and rise to 24% in 2007.

Table 6-21 shows inputs to the UEC calculation and Table 6-22 shows inputs used to calculate savings for Energy Star power management enabled units.

Table 6-21. Vending machines daily UEC by capacity in year 2007

Capacity (cans/unit)	REF (kWh/day)	Energy Star Tier 1 (kWh/day)	Energy Star Tier 2 (kWh/day)
300	8.5	6.3	5.1
500	10.7	7.2	5.9
600	9.7	7.7	6.3
700	11.5	8.2	6.7
800	9.1	8.7	7.1

Table 6-22. Component annual unit energy consumption (example 300-can unit in 2007)

Vending Machine 300 Can Capacity (kWh/day)			
Component	**REF**	**Energy Star Tier 1**	**Energy Star Tier 2**
Compressor	3.8	2.6	2.2
Fan	1.8	0.6	0.5
Lighting	2.1	1.9	1.6
Other	0.8	1.1	0.9
Total (rounded)	8.5	6.2	5.1

The REF and Energy Star UECs are calculated according to Equation 5-19 through Equation 5-22. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Ice Maker

This product category covers air-cooled ice makers that provide cubed ice. Ice makers dispensing flake or nugget ice are not covered. There are three covered technology types: ice maker head (IMH), self-contained units (SCU), and remote condenser units (RCU). Each technology has three harvest rate bins.

Unit Sales Data

Total U.S. sales data are from a market assessment by the Cadmus Group (1999b). Total U.S. sales were then disaggregated into technology types and capacities based on personal communication with ICF Consulting (ICF 2005a). We do not have data on Energy Star shipments; the shipment estimates are calculated using the total shipments and an LBNL estimate of the Energy Star market penetration rate. The initial penetration rate estimate of 15% was assumed, with 5% growth per year, until 60% market penetration rate was achieved in 2017, after which the penetration rate is held constant.

Key Baseline Assumptions

The reference case market penetration is different for each technology-capacity bin, ranging from 14% to 50%; the average is 22%. In all cases the reference case market penetration is constant over time and is based on manufacturer test data collected by U.S. EPA during specification development. The free rider market penetration is set to 10%, meaning that slightly more than half the models that were able to meet the performance specification prior to the program did not participate in the program. Our REF UEC is held constant through time.

Modeling Data for Calculating Energy Star Savings

The reference case and Energy Star UEC is taken from test data submitted by Energy Star partners during specification development. Ice makers do not have operational modes or power management. We assume an annual usage of 273 days per year.

The REF and Energy Star UECs are calculated according to Equation 5-18. The UES is calculated according to Equation 5-26 and Equation 5-28. Energy Star program savings are calculated according to Equation 4-1.

6.5. Computer

Product Category Description

A computer is a device that performs logical operations and processes data. Computers include desktop units, notebook units, and workstations.

Energy Star Performance Criteria

The Energy Star performance criteria are outlined in Table 6-23.

Table 6-23. Energy Star computer Tier 1 requirements

Product Type	Tier 1 Requirements
Desktop	Standby (Off Mode): ≤ 2.0 W Sleep Mode: ≤ 4.0 W Idle State: Category A: ≤ 50.0 W Category B: ≤ 65.0 W Category C: ≤ 95.0 W
Notebook	Standby (Off Mode): ≤ 1.0 W Sleep Mode: ≤ 1.7 W Idle State: Category A: ≤ 14.0 W Category B: ≤ 22.0 W
Workstation	TEC Power (P_{TEC}): ≤ 0.35 * [P_{Max} + (# HDDs * 5)] W *Note: Where Pmax is the maximum power drawn by the system and #HDD is the number of installed hard drives in the system.*

Desktop Computer

This category covers computers where the main unit is intended to be located in a permanent location, often on a desk or on the floor. We model the residential and commercial sector separately, due to the difference in usage patterns and equipment lifetimes between the two building sectors.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods (Gartner 2001; IDC 2007). These reports provide shipments from 1993–2010. From 2011–2025, desktop sales are projected to decrease at an average rate of -1.6% as desktop market share is replaced by notebook computers. The growth rate is calculated using declining shipments as reported by IDC (2007). The breakdown of computer sales between the residential and commercial sector is calculated from several industry sources. From 1993 to 2003, sales by building sector are taken from Gartner 2001. Sales by sector for 2003 and 2004 are from CEA (2004). Building sector sales for 2006–2009 are estimated from IDC (2006d),

which reported a residential share of 43% in 2010. All other years are extrapolated based on these published sources.

Energy Star sales in 1993, 1994, 1995, 1999, and 2000 are estimated by information technology (IT)-based market research firms by matching manufacturer-reported sales for each model with U.S. EPA's Energy Star-qualified computer model list for each given year (Dataquest 1994, 1996; Gartner 2001). All other years through 2007 are held constant at the documented market penetration (for example 2005 is held constant at the 2000 level). Energy Star sales in 2008 and beyond are LBNL estimates. Partners began reporting Energy Star sales to U.S. EPA in 2008.

Key Baseline Assumptions

The reference case market penetration is 0%. Prior to Energy Star computers (pre-1993), power management was not available on desktop computers. Energy Star transferred notebook power management technology to the desktop market by requiring that models meet power requirements in low-power modes to qualify for Energy Star. We assume a reference case market penetration of 0% throughout the analysis period, which means that Energy Star is attributed full credit for all Energy Star unit sales. Since the reference case market penetration is 0%, there is no free-ridership for Energy Star computers and all Energy Star unit sales in any given year are attributed to U.S. EPA.

Modeling Data for Calculating Energy Star Savings

The computer REF UEC incorporates an *on* mode and an *off* mode. The UEC varies, based on whether a unit is turned off after use (only 36% of units in the office sector and 79% of units in the residential sector). From 1993–2007, Energy Star savings were realized only if a unit power-managed successfully (7% of units in the office sector and 15% of units in the residential sector) and/or a unit was turned off after use (same percent assumptions as our REF). Our usage assumptions (including days of use, hours of use by mode, and equipment turn off and enabling rates) are from Media Metrix (2001); Piette et al. (1995); Webber et al. (2001); Tiax (2006); and Roberson et al. (2004). REF *active* and *idle* mode power consumption is measured data from LBNL (Roberson et al. 2002), ECOS Consulting (Calwell 2000), U.S. EPA (2007c), and industry. *Off* mode power consumption is measured data from LBNL (Roberson et al. 2002).

From 1993 to 2007, Energy Star *active* and *idle* power is equivalent to REF *active* and *idle* power. Beginning in 2008, Energy Star *on* power is the maximum *on* power allowable under the current specification. Energy Star *sleep* and *off* mode power consumption represents the maximum allowable power levels.

Table 6-24. Calculation methodology for Energy Star office desktop computer in 2008

Office Desktop Computer	REF	Energy Star
Active (W)	115	109
Idle (W)	84	60
Sleep (W)	NA	5
Off (W)	3	3
Active (hrs/day)	1	1
Idle (hrs/day)	9	3
Sleep (hrs/day)	NA	6
Off (hrs/day)	15	15
Active (hrs/yr)	201	201
Idle (hrs/yr)	1,705	602
Sleep (hrs/yr)	NA	1,104
Off (hrs/yr)	6,854	6,854
% of units left on after use	64%	64%
% of units power managing	NA	8%
% units turned on per day	76%	76%
Days of use per year	264	264
UECs (kWh/yr)		
-Turned off, not power managing	187	141
-Left on, not power managing	741	535
-Turned off, power managing	NA	80
-Left on, power managing	NA	94
-Weighted Average	541	370

Notes to Table 6-24:
• Hours may not sum to 24 due to rounding.
• 2008 is the effective date of revised specification.

The REF and Energy Star UECs are calculated according to Equation 5-1 through Equation 5-3. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

Notebook Computer

A notebook computer is designed specifically for portability and to be operated for extended periods of time without a direct connection to an AC power source. We model the residential and commercial sector separately, due to the difference in usage patterns and equipment lifetimes between the two building sectors.

Unit Sales Data

Total U.S. sales data are from IDC 2006d. This report provides shipments (shipments are a proxy for sales) from 2003 to 2010. The notebook module begins in 2000 and data for 2000–2002 are simply extrapolated from the 2003 data point from IDC (2006d). From 2011–2025, notebook

sales are projected to increase at an average rate of 1.5% as notebook market share displaces desktop computers. The growth rate is calculated using increasing shipments as reported by IDC (2006d). We adopt the breakdown of desktop sales (described above) between the residential and commercial sector as a proxy for the breakdown of notebook sales by sector.

Through 2007, Energy Star sales comprised 100% of the market. Energy Star sales in 2008 and beyond are LBNL estimates. Partners started to report Energy Star sales to U.S. EPA in 2008.

Key Baseline Assumptions

Through 2007, the reference case penetration is 100%, since all notebooks were able to meet the Energy Star specification and power management already existed on notebook computers prior to U.S. EPA's involvement in the market. The reference case penetration is reduced to 22% beginning in 2008, with the implementation of new idle mode requirements for notebooks. We set the free rider penetration equal to the reference case penetration. Our REF takes into account increasing power consumption due to processor requirements and memory requirements. Our REF also takes into account reductions in power consumption due to the Energy Star external power supply program and the federal minimum efficiency standard for external power supplies, which is effective in 2009.

Modeling Data for Calculating Energy Star Savings

REF *active*, *idle sleep*, and *standby* wattages for 2005–2025 are from the U.S. EPA (EPA 2007c) manufacturer test dataset that was assembled to develop the current specification. Prior to 2005, we adjust wattages based on historic power supply efficiency data that was obtained from Ecos Consulting (Calwell 2000). The charge mode wattage is based on LBNL metering of notebook computers (Roberson 2002). Usage patterns are estimated from Piette et al. (1995). We assume that 64% of units are left on 24 hours per day and that 75% are used as the primary computer via a docking station. Primary computers have the same usage pattern as desktop computers, with the exception of turn off and enabling rates, which are specific to notebook computers. Turn off and enabling rates are taken from Webber et al. 2001 and Roberson et al. 2004. Since usage patterns are different for primary versus secondary notebooks, we calculate the UECs separately and then create a weighted average UEC using our estimate of the percentage of units that are primary versus secondary units.

The Energy Star UEC reflects the same five power-consuming modes. Idle mode power criterion was not established until 2008. From 1993 to 2007, Energy Star *active* and *idle* mode power is the same as REF *on* mode power. Beginning in 2008, Energy Star *idle* mode power is set to the maximum power consumption allowable under the specification. This criterion is based on the category of notebook computer (described above). At this point, savings realized in *idle* mode (measured in watts) are expected to transfer to *charge* and *active* mode as well (power supply improvement, component efficiencies, and similar improvements are directly transferable to *active* mode), and the charge and *active* power consumption declines respectively. Energy Star *sleep* and *off* mode power consumption is set to the maximum power consumption allowable under a given specification level throughout the analysis period. Table 6-25 shows our

calculation methodology for an Energy Star office notebook computer in 2008 (the example shows a secondary computer). All secondary notebooks are assumed to be shut off after use.

The REF and Energy Star UECs are calculated according to Equation 5-1 through Equation 5-3. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

Table 6-25. Calculation methodology for Energy Star notebook computer in 2008

Office Secondary Notebook	REF	Energy Star
Charge (W)	21	18
Active (W)	20	16
Idle (W)	20	16
Sleep (W)	1	1
Off (W)	1	1
Charge (hrs/day)	1	1
Active (hrs/day)	1	1
Idle (hrs/day)	2	2
Sleep (hrs/day)	6	6
Off (hrs/day)	5	5
Charge (hr/yr)	90	90
Active (hrs/yr)	90	90
Idle (hrs/yr)	180	180
Sleep (hrs/yr)	540	540
Off (hrs/yr)	450	450
% of units left on after use	0%	0%
% of units power managing	17%	17%
% units turned on per day	100%	100%
Days of use per year	90	90
UECs (kWh/yr)		
-Turned off, not power managing	18	15
-Turned off, power managing	8	7
-Weighted Average	17	14

Note: Hours may not sum to 24 due to rounding.

Workstation

U.S. EPA defines a *workstation* as a device that:

- is marketed as a workstation;
- has a mean time between failures (MTBF) of at least 15,000 hours based on either Bellcore TR-NWT-000332, Issue 6, 12/97 or field-collected data; and
- supports error-correcting code (ECC) and/or buffered memory.

Unit Sales Data

We do not have published sales data for units that directly match U.S. EPA's definition (above). Instead, we use total U.S. sales data referenced in the desktop section and allocate a percentage of those sales to the workstation market (our allocation percentage is 2%). The percent allocation is derived from personal communication with Tom Bolioli of Terra Novum Consulting, who was the technical lead on the Energy Star computer specification revision in 2008. We assume all workstations are sold to the commercial sector.

Key Baseline Assumptions

The reference case market penetration is consistent with desktop computers: 0%. Since the reference case market penetration is zero, there is no free-ridership for Energy Star computers, and all Energy Star unit sales in any given year are attributed to U.S. EPA.

Modeling Data for Calculating Energy Star Savings

The REF UEC reflects a total annual energy consumption estimate based on manufacturer energy consumption test data that was submitted during the 2008 specification revision process. Our REF is held constant over time and is set at 1,254 kWh/yr. The Energy Star UEC is set as the maximum allowable energy consumption under the current specification (915 kWh/yr for an average machine).

The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

6.6. Display

Product Category Description

Electronic displays include Energy Star monitors (launched in 1993) and Energy Star televisions (launched in 1998).

Energy Star Performance Criteria

Energy Star criteria have been different for monitors and televisions.

Monitors:

From 1993 to 2004, Energy Star-qualified monitors were required to meet low power mode criteria. These criteria required manufacturers to ship Energy Star units with power management features enabled and established power consumption levels for the sleep and off mode.

Beginning in 2005, Energy Star-qualified monitors were required to meet *on* mode performance criteria in addition to *sleep* and *off* mode requirements. The current Energy Star monitor requirements are based on a unit's native resolution, and are as follows:

Table 6-26. Energy Star monitor version 4.0 requirements

Product	On mode (W)	Sleep mode (W)	Off mode (W)
< 1 megapixel	23	2	1
≥ 1 megapixel	0.28*megapixels	2	1

Televisions:

From 1998 through 2007, Energy Star-qualified televisions were required to meet *standby* mode criteria. Beginning in November 2008, Energy Star-qualified televisions were required to meet *on* mode performance criteria in addition to *standby* requirements. The current Energy Star television requirements are based on a unit's resolution and screen area, as shown in Table 6-26.

Table 6-27. Energy Star television version 3.0 requirements

Product Native Vertical Resolution	Product Screen Area (in^2)	On mode (W)	Off mode (W)
≤ 480	All	0.12*A+25	1
> 480	$A < 680\ in^2$	0.20*A+32	1
> 480	$680\ in^2 \leq A < 1045\ in^2$	0.24*A+27	1
> 480	$A \geq 1045\ in^2$	0.156*A+151	1

Monitor

This product category covers standard desktop computer monitors. Common display technologies include liquid crystal display (LCD) and cathode-ray tube (CRT). We model these technologies separately due to the difference in *on* mode power consumption and usage patterns between the two technologies. We also model the residential and commercial sector separately due to the difference in usage patterns and equipment lifetimes between the two building sectors.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods and are disaggregated between office and residential sales of CRT and LCD monitors (Gartner 2001; IDC 2001, 2003, 2007). Energy Star unit sales are a combination of industry-market research studies and manufacturer-reported sales of Energy Star units (Dataquest 1994; Garter 2001; ICF 2006b, 2007, 2008).

Key Baseline Assumptions

Prior to Energy Star monitors (pre-1993), power management was not available on desktop monitors. Energy Star transferred laptop power management technology to the monitor market by requiring that models meet power requirements in low-power modes to qualify for Energy Star. We assume a reference case market penetration of 0% throughout the analysis period, which means that Energy Star is attributed full credit for all Energy Star unit sales. Since the

reference case market penetration is 0%, there is no free-ridership for Energy Star monitors. Improvement in external power supply efficiency (due to Energy Star and due to the federal standard) is factored into the LCD REF.

Modeling Data for Calculating Energy Star Savings

Our REF UEC only incorporates an *on* mode and an *off* mode. The UEC varies, based on whether a unit is turned off after use (only 18% of units in the office sector and more than 95% of units in the residential sector). REF power consumption for *on* and *off* mode is measured data from LBNL metering (Roberson et al. 2002). Our usage assumptions (including days of use, hours of use by mode, and equipment turn off and enabling rates) are estimates from Media Metrix (2001); Piette et al. (1995); Nordman et al. (1998); Webber et al. (2001); Roberson et al. (2004); and Porter et al. (2006).

From 1993 to 2004, Energy Star savings were realized only if a unit power-managed successfully (81% of units in the office sector and 40% of units in the residential sector) and/or a unit was turned off after use (same percent assumptions as our REF). From 1993 to 2004, Energy Star *on* power is equivalent to REF *on* power. Beginning in 2005, Energy Star *on* power is the maximum *on* power allowable under the Version 4.0 specification (weighted by screen area). Energy Star *sleep* and *off* mode power consumption represents power levels achieved by qualified Energy Star units in a given year as reported to U.S. EPA by manufacturing partners.

Table 6-28 shows our calculation methodology for an Energy Star LCD Office Monitor in 2007.

Table 6-28. Calculation methodology for Energy Star LCD office monitor (2007)

Performance	REF	Energy Star
On (W)	49	32
Sleep (W)	NA	1
Off (W)	2	1
On (hrs/day)	10	4
Sleep (hrs/day)	NA	6
Off (hrs/day)	15	15
On (hrs/yr)	1,906	803
Sleep (hrs/yr)	NA	1,104
Off (hrs/yr)	6,854	6,854
% of units left on after use	82%	82%
% of units power managing	NA	81%
% units turned on per day	76%	76%
Days of use per year	264	264
UECs (kWh/yr)		
-Turned off, not power managing	105	65
-Left on, not power managing	425	277
-Turned off, power managing	NA	31
-Left on, power managing	NA	33
-Weighted Average	367	72

Note: Hours may not sum to 24 due to rounding.

The REF and Energy Star UECs are calculated according to Equation 5-1 through Equation 5-3. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

Television

This product category covers consumer television sets. Common display technologies include liquid crystal display (LCD), cathode-ray tube (CRT), projection, and plasma display panel (PDP). We model these technologies separately due to differences in *on* mode and *standby* mode power consumption between the technologies.

Unit Sales Data

Total U.S. sales data are from industry-based market research reports spanning several time periods and are disaggregated by technology and screen size (Peck 2000); *Appliance Magazine* 2003; CEA 2001, 2003; Patel 2005; DisplaySearch 2007). Energy Star unit sales (1999–2007) are manufacturer-reported sales of Energy Star units (CEA 2001, 2003; ICF 2004, 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

The reference case market penetration is based on LBNL metering circa 1998 and is set to 2% (held constant over time). The free rider market penetration is also set to 2%. All technologies have the same reference case baseline. We also account for the following REF trends:

- Increasing *on* power for LCDs, Projection TVs, and Plasma TVs due to increasing screen size
- Decreasing *on* power for CRT TVs beginning in 2005. The power decrease which was designed to capture improvements in CRT technology driven by the Energy Star monitor specification (these improvements were substantiated by metered data from CNET and manufacturer sources)
- Decreasing *standby* power for LCD TV and PDP TVs (documented through test data for non-qualified products)
- Improvement in external power supply efficiency for LCD TVs

Modeling Data for Calculating Energy Star Savings

REF *on* power is measured data taken from a variety of sources depending on technology (Rosen and Meier 1999b, CNET 2005, 2007). REF standby power is measured data from LBNL (Floyd and Webber 1998) for CRTs and from CNET (2005, 2007) for all other technologies. Through 2008, Energy Star *on* power is equal to REF minus improvements that had been made to reduce standby consumption that carry over into *on* mode power reductions. Beginning in 2009, Energy Star *on* mode power consumption is equal to the maximum power allowable under the Version 3.0 specification. Energy Star standby power represents levels achieved by qualified models and is from ICF (2002) and U.S. EPA (2006). We assume a TV is used 351 days per year and five

hours per day (Roth and McKenney 2007). Our usage pattern is based on a household phone survey. Table 6-29 shows our calculation methodology for an Energy Star LCD TV in 2009.

Table 6-29. Calculation methodology for LCD TV (2009 specification revision)

Performance	REF	Energy Star
On (W)	182	165
Standby (W)	8	1
On (hrs/day)	5	5
Standby (hrs/day)	19	19
% units turned on per day	100%	100%
Days of use per year	351	351
UEC (kWh/yr)	379	296

The REF and Energy Star UECs are calculated according to Equation 5-1 through Equation 5-3. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-2.

6.7. External Power Supply (EPS) and Battery Charging System (BCS)

Product Category Description

Energy Star Power Supplies includes External Power Supplies, also sometimes referred to as *External Power Adapters,* and Battery Charging Systems.

Energy Star Performance Criteria

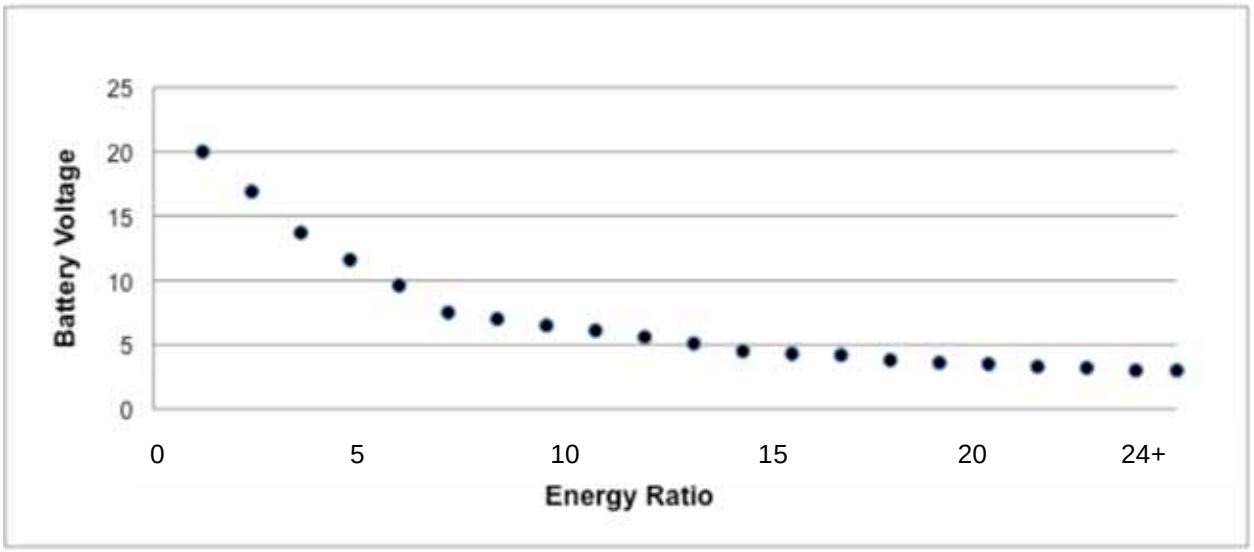
To qualify for the Energy Star label, external power adapters must meet energy efficiency criteria based on the unit's output power rating. Tier 1 of the program was effective starting in 2005; Tier 2 in 2009. The current (Tier 2) Energy Star efficiency requirements are shown in Table 6-30.

Table 6-30. Energy-efficiency criteria for External Power Supply in active mode

Nameplate Output Power (Pno)	Standard Models (efficiency)	Low-Voltage Models (efficiency)
0 to ≤ 1 W	≥ 0.480 * Pno + 0.140	≥ 0.497 * Pno + 0.067
> 1 to ≤ 49 W	≥ [0.0626 * Ln (Pno)] + 0.622	≥ [0.0750 * Ln (Pno)] + 0.561
> 49 W	≥ 0.870	≥ 0.860

To qualify for the Energy Star label, a BCS must not exceed a maximum non-active Energy Ratio, which is a measure of the fraction of the useful energy stored in the battery that is lost in non-active (standby) mode, and is based on the nominal battery voltage (Vb). The energy ratio requirement is summarized in Figure 6-1.

Figure 6-1. Energy Star performance requirements for Battery Charging Systems (BCS)



External Power Adapter

An external power adapter or external power supply (EPS) is a device designed to convert line voltage AC input into lower voltage AC or DC output for use by a separate end-use device. The Energy Star specification covers only single-voltage EPS and those with a nameplate output power less than 250 watts. The specification has requirements for efficiency in *active* mode, energy consumption in *no-load* (disconnected) mode, and power factor correction. The savings estimates account only for the first of these three factors. We do not have broad data on power supply disconnect times; similarly, we have little data on many factors that would be involved in modeling power factor.

Unit Sales Data

Shipment data are from the Darnel Group's "External AC-DC Power Supplies, Worldwide Forecast" (Darnell 2008). U.S. shipments are derived from Darnel's figures for North America. We assume that the United States accounts for 85% of these devices. We also have shipment estimates for each device, which are used to average the device-specific estimates (e.g., UECs) to get bin-level figures. Some end uses commonly use external power supplies, mostly portable devices like cellular telephones or portable music players. Others like computer monitors or televisions may use either external or internal power supplies. Additionally, some portable devices may not use external power supplies but rely on batteries or battery charging systems. The percentage of each end use that uses an EPS is multiplied by the estimated stock and shipments to arrive at estimates for units with EPS.

Key Baseline Assumptions

The reference case penetrations prior to 2009 are shipment-weighted averages of the estimates for the specific devices, so they vary among the bins. Starting in 2009 the reference case market

penetrations are the percentage of models in the manufacturer's test data that meet the Energy Star criteria. The reference case market penetrations decline sharply with the introduction in 2009 of Energy Star Tier 2. In 2009 the range of reference case market penetrations is from 21% (2.5–5 W) to 4% (> 100 W). The free rider market penetrations for each product are set equal to the reference case market penetration.

We also account for the following REF trends:

- A federal standard for external power supplies equal to Energy Star Tier 1 became effective in 2009, resulting in a declining REF UEC.
- Some products (e.g., televisions, laptop computers) already had power supply improvements embedded in their REF estimates; in these cases those effects were backed out to avoid double-counting.

Modeling Data for Calculating Energy Star Savings

We divide external power supplies into eight output power bins. Products that use EPS are assigned to bins based on an estimate of the power supply output power, using the ratio of active power to nameplate output power (Sawyer 2004). For each product within a bin, a REF UEC is obtained. Some of these UECs are based on operational modes and others are taken from the literature or product testing data. The Energy Star UEC is calculated by multiplying the REF UEC by the ratio of the REF and Energy Star efficiencies. THE REF efficiencies come from a number of sources and are described in the following section. The Energy Star efficiencies are from the manufacturer-submitted data submitted for the specification development. The REF and Energy Star UECs for each bin are the weighted averages of the UECs for the assigned products. The efficiencies and UECs for external power adapters are summarized in Table 6-31.

The Energy Star savings are based on the difference between the REF and Energy Star efficiencies for each bin.

Inputs to the product-specific UEC calculations

The main inputs to the product level REF efficiencies and UECs come from Ecos Consulting (Calwell and Reed 2001 and Calwell 2003). Other sources are cited below in product descriptions.

MP3 Player: The average EPS efficiency in 2002–2008 is taken from power supply curves based on Ecos product metering. The reference case UEC for these devices is calculated from time and energy in operational mode. The energy consumptions and time in modes are from product testing by Ecos Consulting. Units are modeled as having about approximately 1 hour a day *active* use, 5.5 hours in *standby* and *idle* modes, and unplugged the remaining 12 hours. All models are assumed to use EPS, so the percentage of units with EPS is set to 100%.

PDA: The average EPS efficiency in 2002–2008 is taken from power supply curves based on Ecos product metering. The reference case UEC for these devices is calculated from time and energy in operational mode. The energy consumptions and time in modes are from product testing by Ecos Consulting. Units are modeled as having about 1 hour a day *active* use, 5.5 hours

in *standby* and *idle* modes, and unplugged the remaining 12 hours. All models are assumed to use EPS; the percentage of units with EPS is set to 100%.

Table 6-31. Modeled devices, efficiencies, and UECs for external power adapters

Bin	Nameplate Power (W)	Modeled Devices	REF (2005)		Energy Star Tier 1 (2005)		Energy Star Tier 2 (2009)	
			Eff.	UEC	Eff.	UEC	Eff.	UEC
1	< 2.5	MP3 Player PDA Caller ID	35%	2.1	49%	1.5	57%	1.1
2	2.5–5	Cellular Phone	54%	6.1	61%	5.4	71%	4.7
3	5–7.5	Security System Answering Device Cordless Phone	55%	44	65%	37	75%	33
4	7.5–10	Digital Camera Combo Phone	42%	21	69%	13	80%	7
5	10–20	CD player, portable LAN equipment	51%	65	73%	46	81%	39
6	20–50	Inkjet Printer MFD-Inkjet Laptop A Broadband Modem	58%	114	81%	82	85%	89
7	50–100	Laptop B LCD Monitor Scanner	64%	162	84%	124	88%	123
8	> 100	TV (LCD)	64%	260	84%	199	88%	277

Notes to Table 6-31:
- Starting in 2009 the REF efficiency is set by the federal standard to the Energy Star Tier 1 value.
- Laptop A indicates notebook computers without a discrete graphics processing unit, Laptop B indicates a unit so equipped.
- Numbers are rounded.

Caller ID: The average EPS efficiency in 2002–2008 is taken from power supply curves based on Ecos product metering. The reference case UEC is based on product testing by Ecos Consulting. Caller ID devices are modeled to run continuously with only one operational mode. The proportion of units with external power supplies is set to 50%, based on previous LBNL analysis (Webber 2007).

Wireless (cellular) telephone: The average EPS efficiency in 2002–2008 is based on product testing by Cadmus Consulting. The UEC for these devices is calculated from time and energy in operational mode. Energy uses in each mode is from product testing by Cadmus. The number of hours in each mode is from Ecos. We model 2 hours a day in *active* mode, 10 hours in *standby*, 8 *off*, and 4 unplugged. 100% of models are assumed to have external power supplies.

Home Security System: The average EPS efficiency in 2002–2008 is from the power supply curves based on Ecos product metering curves as cited in previous LBNL estimates (Webber 2007). Units are modeled to use 5 watts and to run continuously with a single operational mode.

These assumptions are from previous LBNL power supply analysis (Webber 2007) and are based on commercial units. The proportion of units with external power supplies is set to 100%.

Answering Machine and Cordless and Combination Phone: The UEC for these devices reflects the non-Energy Star efficiency, not the average. The UEC for these devices are not calculated from time and energy in operational mode, but are treated as having a given UEC in 2002–2008. The UEC estimate is from Rosen et al. (2001). The proportion of units with external power supplies is set to 100%.

Digital Camera with Charger: The average EPS efficiency in 2002–2008 is from the power supply curves based on Ecos product metering as used in the previous LBNL power supply analysis (Webber 2007). The REF UEC for these devices is calculated from time and energy in operational mode. Time and energy in modes are from product testing data from Cadmus. Units are modeled as having about 1 hour a day *active* use, 5.5 hours in *standby* and *idle* modes, and unplugged the remaining 12 hours. Only devices with external chargers are modeled here, so the percentage with external power supplies is 100%; cameras with batteries or battery chargers are separated out in the shipments.

Portable CD Player: The UEC for these devices reflects the non-Energy Star efficiency, not the average. The reference case UEC for these devices is calculated from time and energy in operational mode. Energy use figures through 2008 in *active, standby,* and *sleep* are from the LBNL/Florida Solar Energy Center (FSEC) database (Floyd and Webber 1998). Time in mode is based Ecos product testing showing 1% of time is spent in *active* mode, and all remaining time is allocated to *off* mode. The proportion of units with external power supplies is set to 10% of all CD players.

LAN Equipment: The UEC for local area network (LAN) devices reflects the non-Energy Star efficiency, not the average. This is a somewhat heterogeneous product category, containing network hubs, switches and routers, and printer hubs. These devices are modeled to be in continuous operation with a single operational mode. The reference case unit active power is calculated from data from previous LBNL estimates (Webber 2007) and is based on estimates of energy per port, and ports per device. The percentage of units with external power supplies is set to 10%, and was also calculated from data from previous LBNL estimates (Webber 2007).

Imaging, Inkjet: The UEC for these devices reflects the non-Energy Star efficiency, not the average. The reference case UEC for these devices is calculated from time and energy in the operational mode. *Active, standby,* and *idle* mode power through 2008 is from LBNL metering (Lee et al. 2000). Time in *active* mode is assumed to be the same as the lowest-speed laser printer: 0.08 hrs/day. Time in *standby* mode is 8 hrs/day, corresponding to a business day, and the remainder is assigned to *idle* mode. The proportion of units with external power supplies is set to 31%, based on the original LBNL power supply analysis (Webber 2007).

MFD-Inkjet: The UEC for inkjet multifunction devices reflects the non-Energy Star efficiency, not the average. The reference case UEC for these devices is calculated from time and energy in the operational mode. Energy in *active, standby,* and sleep modes through 2008 are from the Star Database 1/04 (Webber 2001). Total time in use per day is from Nordman et al. (1998). The

6 hours total time in use is allocated ½ hour to *active,* 1 hour to *standby/idle,* and 4.5 hours to sleep mode per day. The remaining 18 hours per day are allocated to *off* mode. The proportion of units with external power supplies is set to 8% based on the original LBNL power supply analysis (Webber 2007).

Laptop Computer: The UEC for these devices reflects the non-Energy Star efficiency, not the average. Laptop computers are divided into two sub-types based on power use. Laptop computers are used in both residential and office environments, and because the usage pattern is different in the two environments they are analyzed separately. The UECs in the power supply analysis are taken directly from the product data elsewhere in the model and are the weighted averages of the residential and office types. The proportion of units with external power supplies is set to 100%.

Broadband Modem (Cable or DSL): The average EPS efficiency in 2002–2008 is from the power supply curves based on Ecos product metering as used in the previous LBNL power supply analysis (Webber 2007). These devices are modeled to be in continuous operation with a single operational mode. Unit active power is from Webber (2007). The proportion of units with external power supplies is set to 100%.

LCD Computer Monitor: The UEC for these devices reflects the non-Energy Star efficiency, not the average. Like laptop computers, the monitor analysis is divided into residential and office sectors. The UEC for monitors is not directly calculated as part of the EPS analysis but is the shipment-weighted average of the non-Energy Star UECs from the product analysis. Because the REF UEC includes the effect of EPS, there is an adjustment factor after 2005 to back out that effect from the REF UEC. The estimate of 55% of LCD monitors having EPS is based on the comparison of Darnell's estimate (Darnell 2008) of EPS shipments within the LCD monitor "sector" and the total shipment estimates for LCD monitors.

Scanner (Flatbed): The UEC for these devices reflects the non-Energy Star efficiency, not the average. The reference case UEC for these devices is calculated from time and energy in the operational mode. The energy used in *active, standby, and idle* modes through 2008 is based on LBNL metering (Roberson 2000). The total time in use per day is from Piette et al. (1995). The 7.7 hours time in use is allocated 0.1 hour to *active,* 0.5 hour to *standby,* and 7.1 hours to *sleep* mode per day. The remaining 16 hours per day are allocated to off mode. The percent of units with EPS is set to 100%.

TV (LCD): The UEC for these devices reflects the non-Energy Star efficiency, not the average. The reference case UEC for these devices is calculated from time and energy in the operational mode. Televisions have two operational modes: *active* and *standby.* Energy in the two modes is from CNET's television metering dataset (CNET 2005). Time in *active* mode is from Roth et al. (2007), which estimated time in *active* mode at 13%. The remainder is assigned to *standby.* Most televisions have internal power supplies, and the percent with EPS is set to 2%.

Battery Charging System

A battery charging system (BCS) is a device intended to replenish the charge in a rechargeable battery. The battery charger will connect to the mains at the power input and connect to the battery at the output. The charger may be comprised of multiple components, in more than one enclosure, and may be all or partially contained in the end-use product. Energy Star battery charging systems include rechargeable batteries or battery packs, and battery chargers.

Battery packs are assemblies of one or more rechargeable cells intended to provide electrical energy to an end-use product. Rechargeable cells are any of a number of established cell chemistries intended for repetitive charge/discharge cycles. Primary alkaline cells are not considered rechargeable. Batteries may be either detachable or integral with the end-use product.

In our analysis we divide battery-charging systems into floor care, kitchen appliances, personal care, power tools, and universal chargers.

Unit Sales Data

Total U. S. shipment data for 2002–2003 are from the BCS Market Report by ICF (2005b); subsequent years are estimated using LBNL's estimate of 1% growth per year. Energy Star shipments are also from the ICF BCS Market Report.

Key Baseline Assumptions

The reference case market penetration of high-efficiency units is based on analysis by Cadmus Consulting for the draft specification. The reference case market penetration for each product is constant over time, but the penetration rate varies among products. The average penetration rate is 27%. The free rider market penetration is set to zero for all products, because of low participation in the program. Because there are high-efficiency units on the market that do not participate in the program, the non-Energy Star UEC is lower than the REF UEC. We do not model any changes to the baseline case.

Modeling Data for Calculating Energy Star Savings

We model BCS as exogenous annual UEC products. The reference case and Energy Star UECs are both taken from product metering by Cadmus Consulting. The unit energy savings are the difference between the non-Energy Star and the Energy Star UECs.

Table 6-32. Summary of Battery Charging System (BCS) UECs

	Baseline (kWh/yr)	Energy Star (kWh/yr)	Non-Energy Star (kWh/yr)	Baseline Market Pen. Rate (%)
Floor Care	15	13	15	38
Kitchen Appliances	8	5	8	21
Personal Care	15	11	14	29
Power Tools	32	16	29	23
Universal Battery Charger	22	14	20	21
Weighted Average BCS	21	13	19	27

Note: values have been rounded.

6.8. Heating, Ventilation, and Air Conditioning (HVAC)

Product Category Description

The Energy Star HVAC program covers furnaces (gas and oil), boilers (gas and oil), central air conditioners (CAC), air-source heat pumps (ASHP), geothermal heat pumps, programmable thermostats, and light commercial HVAC.

Energy Star Performance Criteria

The following criteria must be met:

Table 6-33. HVAC Energy Star performance criteria

Product	Energy Star Criteria
Air Source Heat Pump (ASHP)	≥ 8.2 HSPF/ ≤14.5 SEER/ ≥12 EER* for split systems ≥ 8.0 HSPF/ ≥14 SEER/ ≥11 EER* for single package equipment, including gas/electric package units
Boiler	≥ 85 AFUE
Central Air Conditioner (CAC)	≥ 14.5 SEER/ ≥12 EER* for split systems ≥ 14 SEER/ ≥11 EER* for single package equipment including gas/electric package units
Furnace	≥ 90 AFUE for gas units ≥ 85 AFUE for oil units
Geothermal Heat Pump (HP)	Open Loop: ≥ 3.6 COP; ≥ 16.2 EER Closed Loop: ≥ 3.3 COP; ≥ 14.1 EER Direct Expansion (DX): ≥ 3.5 COP; ≥ 15 EER
Light Commercial HVAC - HP	
< 65,000 Btu/h	13 SEER; 7.7 HSPF
65,000 Btu/h – < 135,000 Btu/h	10.1 EER (10.4 IPLV); 3.2 COP
135,000 Btu/h – 250,000 Btu/h	9.3 EER (9.5 IPLV); 3.1 COP

Table 6-33, (Continued)

Product	Energy Star Criteria
Light Commercial HVAC - AC	
< 65,000 Btu/h	13 SEER
65,000 Btu/h – < 135,000 Btu/h	11.0 EER; 11.4 IPLV
135,000 Btu/h – 250,000 Btu/h	11.0 EER; 11.4 IPLV
Programmable Thermostat	Shipped with a default energy saving program that is capable of maintaining two separate programs (to address the different comfort needs of weekdays and weekends) and four temperature settings or more for each day.

Notes to Table 6-33:
HSPF = heating seasonal performance factor; SEER = seasonal energy efficiency ratio; EER = energy efficiency ratio; AFUE = annual fuel utilization efficiency; COP = coefficient of performance; IPLV = integrated part load value.

Furnaces, Boilers, CAC, ASHP, and Geothermal HP

Furnaces and boilers cover gas- and oil-fired units. Central air conditioners and ASHPs cover residential package and split-system central air conditioners and air source heat pumps. Geothermal heat pumps include open- and closed-loop and direct-expansion units, and multi- and single-speed designs. Energy Star-qualified geothermal heat pumps must also provide some or all domestic hot water demand.

Unit Sales Data

Table 6-34 shows relevant units sales data for the included product categories.

Table 6-34. HVAC sales data

Product Category	Unit Sales	Energy Star unit sales
Furnace	Total U.S. sales (1996–2006) are from *Appliance Magazine's* Statistical Reviews (Appliance Magazine 2006, 2007a)	Partner-reported sales for 2004, 2005, 2006, and 2007 (ICF 2006a, 2006b, 2007, 2008)
Boiler	Total U.S. sales (1996–2006) are from *Appliance Magazine's* Statistical Reviews (*Appliance Magazine* 2006, 2007a)	Partner-reported sales for 2003, 2004, 2005, 2006, and 2007 (ICF 2004, 2006a, 2006b, 2007, 2008)
CAC and ASHP	1995: Industry projection from Carrier; 1996–2000 Shipments from ARI (ARI 2001); 2001–2007 from *Appliance Magazine's* Statistical Review (*Appliance Magazine* 2007b)	1996–2000: Industry data from ARI (ARI 2001). 2005–2007 are partner-reported sales (ICF 2006b, 2007, 2008)
Geothermal HP	1995–1996: U.S. DOE/EIA Survey of Geothermal Heat Pump Shipments (U.S. DOE 2000). 1999–2005 from DOE/EIA Survey of Geothermal HP Shipments, 2005 (July 2007)	Partner-reported sales for 2002, 2003, 2004, 2005, 2006, and 2007 (ICF 2003, 2004, 2006a, 2006b, 2007, 2008)

Key Baseline Assumptions

Furnaces: The initial (1995) reference case market penetration for gas furnaces is set to 22%, which rises to 24% in 1998 and is constant thereafter (industry estimate from Carrier, see Warren 1996). The reference case penetration rate for oil furnaces is much lower, estimated initially at 1%, rising to 4% in 2007, and returning to 2% after the 2009 Energy Star specification revision (LBNL estimate). The free rider market penetration is set equal to the reference case market penetration in all years. The reference case baseline for furnaces is fixed.

Boilers: The reference case market penetration for gas boilers is based the percent of models meeting the Energy Star criterion from the California Energy Commission database (CEC 2001); it is set to 4% through 2013, when it rises to 25%. The increase in the reference case market penetration is due to the assumption that the new federal standard will be implemented that year, increasing the reference case ability to meet the Energy Star criterion in the absence of a specification change. The reference case market penetration for oil boilers is 48% in 1996, zero thereafter (CEC 2001). The free rider market penetration is set equal to the reference case market penetration in all years. A new NAECA standard, which will lower the average new unit energy consumption, is scheduled for introduction in 2013.

CAC and ASHP: The reference case market penetration for CAC is based on data from ARI (2001). Package and split systems have somewhat different penetration rates. On average, the reference case for CAC is 15%, although it varies over time based on specification revisions and changes to the federal standard. For ASHP the initial penetration rate is 26%, and it also varies over time. The free rider market penetration is set equal to the reference case market penetration in all years. A new efficiency standard was effective in 2006, which lowered the average new unit energy consumption.

Geothermal HP: The original LBNL forecast of reference case market penetration of high-efficiency units was based on ARI data. The forecast estimated that all geothermal heat pumps would meet the Energy Star level. However, in 2002 shipments reported by Energy Star partners amounted to 10,909 units, which indicated a 41% market penetration. We reduced the baseline market penetration to 40% for 1995 and assumed that growth in the market would be due to Energy Star. Free rider market penetration in 2002 is adjusted to 85% of reference case shipments since Energy Star sales data was lower than reference case units shipped. In other years free rider market penetration is set equal to reference case market penetration. We do not model any changes to the baseline case.

Modeling Data for Calculating Energy Star Savings

The REF and Energy Star UEC is taken from an energy analysis conducted by LBNL, which used household characteristic data from the Residential Energy Consumption Survey (RECS) (U.S. DOE 1995). Equipment efficiencies (REF is set to a federal standard and Energy Star is set to allowable criteria) were applied to the regional loads to estimate annual space conditioning energy use. Regional housing shares were analyzed to create a national average (Hanford et al. 1994).

In the case of heat pumps, we separately track equipment space heating and cooling consumption. The UEC derived from LBNL's modeling provides a total annual consumption (which includes annual equipment heating and cooling). We assume that heat pumps have a UEC equal to split-system CAC for cooling and the remainder of the annual energy is assigned to heating. Table 6-35 shows UECs for two applicable years (2007 and 2015).

Table 6-35. HVAC REF and Energy Star UECs

Product Category	REF UEC 2007	REF UEC 2015	Energy Star UEC 2007	Energy Star UEC 2015
Gas Furnace (MBtu)	77	77	67	67
Oil Furnace (MBtu)	67	67	63	61
Gas Boiler(MBtu)	103	100	97	97
Oil Boiler (MBtu)	108	103	102	102
ASHP (kWh)	10,900	10,900	9,970	9,910
CAC (kWh)	2,630	2,630	2,260	2,190
Geothermal HP (kWh)	17,400	17,400	12,200	12,200

Note: CAC and ASHP represent the U.S. sales weighted average of split and package units.

Energy Star HVAC equipment sales can be attributed to either Energy Star Homes or Energy Star Product Labeling. To avoid double counting program savings, we first attribute Energy Star unit sales to the Homes program and any remaining sales above the free-ridership level are then attributed to Product Labeling.

The calculation methods differ between HVAC product type:

For furnaces and boilers, and geothermal heat pumps, the UES is calculated according to Equation 5-26 and Equation 5-27, and Energy Star program savings are calculated according to Equation 4-1.

For CAC, the UES is calculated according to Equation 5-26 and Equation 5-27, and Energy Star program savings are calculated according to Equation 4-2.

For geothermal heat pumps, the UES is calculated according to Equation 5-26 and Equation 5-28, and Energy Star program savings are calculated according to Equation 4-2.

Programmable Thermostats

This product category includes only programmable thermostats.

Unit Sales Data

The initial shipment level for programmable thermostats is derived from the stock estimate and the assumption of an average 15-year unit lifetime. Annual shipments are estimated from the initial level, using an industry-reported growth rate of 1.1% per year. Energy Star shipments are

an estimate by LBNL, unlike most other products, sales of Energy Star programmable thermostats are not reported through ICF's annual shipment reports.

Key Baseline Assumptions

The reference case market penetration of high-efficiency units is based on an estimate by Carrier (Warren 1996), which estimated 15%–20% in 1995 and 40%–50% in 10 to 15 years. We used the upper estimate as the initial value and the modeled rate rising to 44% in 2010. The free rider market penetration is estimated by LBNL. The initial (1996) value is set to 16%, and it rises to 31% in 2010. We also account for the following REF trends:

- Changes in the UECs for HVAC equipment are reflected in the savings calculation for thermostats.
- The Energy Star programmable thermostat program is being sunset as of 2011, so there are no savings after 2010.

Modeling Data for Calculating Energy Star Savings

Because there are both Energy Star HVAC units and Energy Star thermostats, the methodology includes steps to avoid double-counting between the two. The underlying assumptions are that all programmable thermostats are installed with new heating/cooling equipment, and that programmable thermostat installations are independent of the HVAC efficiency. The initial (1995) equipment UECs are the baseline UECs from the HVAC product spreadsheets. For subsequent years the market penetration of high-efficiency devices was used to calculate a heating/cooling UEC based on the shipment-weighted efficiency. We only include heating savings. Percent savings are taken from RLW Analytics (RLW Analytics 2007), and they were applied to the year-by-year UECs to get estimated thermostat savings. HVAC saturations (Hanford et al. 1994) are used to weight the thermostat savings, so that when they are totaled, they represent average house savings. The weighted savings are multiplied by the enabling rate for programmable thermostats to account for the fact that not all thermostats that have programmable capability actually use it.

The UES is calculated according to Equation 5-26 and Equation 5-28. Energy Star program savings are calculated according to Equation 4-1.

Light Commercial HVAC

This product category includes split-system and single-package central air conditioners and heat pumps, rated at 65,000 Btu/h or up to 250,000 Btu/h. Three-phase equipment rated below 65,000 Btu/h may also qualify for the label, but this equipment is not modeled separately in our analysis.

Unit Sales Data

The initial shipments are taken from LBNL analysis of the EIA Commercial Building Energy Consumption Survey (CBECS). They are based on estimates of the percentage of application of different space conditioning equipment to commercial buildings, estimates of the conditioned

space of commercial buildings, and the unit lifetimes. Growth of shipments of 1.2% per year is based on the AEO 2000 (US DOE 2000) commercial floor space growth rate 1998–2010. Shipments of light commercial HVAC differ from most other products in that they are not unit shipments but are expressed as amount of floor space conditioned, in millions of square feet.

Key Baseline Assumptions

The initial (1995) reference case market share is equal to 7% in 2002, rising slowly to 10% in 2021 and subsequent years. The free rider market penetration is equal in all instances to the reference case market penetration. As with the sales data, we do not have data on energy consumption per light commercial HVAC unit, but rather use energy consumption per unit of floor area. We also account for the following REF trends:

- The reference case UEC declines slowly from 69 kWh/ft^2/yr in 2002 to 68 kWh/ft^2/yr in 2009, reflecting naturally occurring improvement in non-Energy Star equipment performance.
- A federal standard slated to go into effect in 2010 will raise the average new unit UEC to be equal to the Energy Star level. No savings are modeled after 2009.

Modeling Data for Calculating Energy Star Savings

The reference case and Energy Star UECs are not calculated as part of the model but are taken from the same LBNL analysis of shipment estimates.

Table 6-36. REF and Energy Star UEC

(kWh/ft^2/yr)

Product Category	REF UEC 2007	REF UEC 2015	Energy Star UEC 2007	Energy Star UEC 2015
Small AC (65–135 kBtuh)	83	79	79	79
Small HP (65–135 kBtuh)	87	81	81	81
Large AC (135–250 kBtuh)	52	50	50	50
Large HP (135–250 kBtuh)	67	62	62	62

The UES is calculated according to Equation 5-26 and Equation 5-27, and Energy Star program savings are calculated according to Equation 4-1**.**

6.9. Imaging

Product Category Description

This product category includes copier, facsimile (fax) machine, scanner, printer, multi-function device (MFD), and mailing machine.

Energy Star Performance Criteria

Imaging products may qualify for the Energy Star program by meeting efficiency requirements. The efficiency requirements for TEC products are summarized in Table 6-37.

Table 6-37. Energy Star requirements for imaging products

Product	Product Speed (image per min)	Maximum TEC (kWh/week)
Monochrome copier, duplicators, Fax, printer	≤ 12	1.5 kWh
	12 < x ≤ 50	(0.20 kWh/ipm) -1 kWh
	> 50	(0.80 kWh/ipm) -31 kWh
Color copier, duplicator, Fax, printer	≤ 50	(0.20 kWh/ipm) +2 kWh
	> 50	(0.80 kWh/ipm) -28 kWh
Monochrome MFD	≤ 20	(0.20 kWh/ipm) + 2 kWh
	20 < x ≤ 69	(0.44 kWh/ipm) -2.8 kWh
	> 69	(0.80 kWh/ipm) -28 kWh
Color MFD	≤ 32	(0.20 kWh/ipm) + 5 kWh
	32 < x ≤ 61	(0.44 kWh/ipm) -2.8 kWh
	> 61	(0.80 kWh/ipm) -25 kWh

Imaging products that qualify under the operational mode approach must meet standby power requirements. These standby requirements are summarized in Table 6-38.

Table 6-38. Operational Mode (OM) standby criteria for imaging equipment

Product Type and Size Format	Standby (W)
All Small Format and Standard-size OM Products without Fax Capability	1
All Small Format and Standard-size OM Products with Fax Capability	2
All Large Format OM Products and Mailing Machines	N/A

The OM products modeled are inkjet fax machines, inkjet printers, inkjet MFDs, and scanners.

Unit Sales Data

We divide the analysis of imaging equipment into residential and commercial sectors in order to account for varying usage and market share between home and commercial units.

The main sources for imaging equipment shipments are: Gartner's special report for the Environmental Protection Agency Energy Star Program (Gartner 2001) as well as market research by IDC (IDC 2006a, 2006b, 2006c) and by the Consumer Electronics Association (CEA 2004). The IDC and CEA figures are not disaggregated by commercial versus residential; the disaggregation was conducted by LBNL using market share percentages derived from the Gartner shipment figures. The sources for imaging equipment, by product, are summarized in Table 6-39.

Table 6-39. Imaging equipment sales data

Product Category	Unit Sales	Energy Star unit sales
Copier	U.S. sales 1995–2002 are from Gartner (2001) 2002–2010 are from IDC's Worldwide Copier Forecast 2006–2010 (IDC 2006a)	Energy Star Market Share 1999–2000 Gartner (2001) Other years, LBNL extrapolation
Fax	U.S. sales 1993–1997 are from Gartner (2001) 1998–2004 are based on CEA (2004)	Energy Star Market Share is LBNL estimate.
Printer and MFD	U.S. sales 1993–2001 are from Gartner (2001) 2002–2010 are from IDC (2006b, 2006c). Growth in shipments is calculated from the IDC shipment estimates.	Energy Star Market Share 1999–2000 Gartner (2001) Other years, LBNL extrapolation
Wide Format Printer	U.S. Sales are from Lyra Shipments Summary (Lyra, April 1999). Assumed to be in commercial only.	Energy Star Market Share is LBNL estimate.
Scanner	1997–1998 sales are taken from Guo et al. (1998). Sales for 1999–2003 are taken from *Appliance Magazine,* 51st Annual Report Statistical Review, 2004. Sales 2004–2006 are from *Appliance Magazine* (2006), 54th Annual Appliance Industry Forecast. Shipment figures in other years are LBNL estimates.	Energy Star Market Share is LBNL estimate.

From 2008 on, sales are expected to change at the following average annual rates:

- Copier: Office, 1%; Residential, 0% (no shipments to residential after 2003)
- Fax: -1.8%
- Inkjet fax: -1%
- Monochrome Printer: Office 2%; Residential 0.5%
- Color Printer: Office 3.6%; Residential 10%
- Wide Format Printer: 3%
- Inkjet Printer: Office -5%; Residential -2.5%
- Monochrome MFD: Office .5%; Residential 0.17%
- Inkjet MFD: Office 1.5%; Residential 0.3%
- Scanner: -1%

Energy Star Sales are calculated from the estimate of U.S. Sales and an estimate of the Energy Star market share percent. For copiers, MFDs, and printers other than wide-format, the 1999 and 2000 estimates of the Energy Star market shares are from Gartner (2001). In other years, the Energy Star market share is an LBNL extrapolation from the Gartner figures. For faxes, scanners, and wide-format printers, the Energy Star market share estimates are all by LBNL.

Key Baseline Assumptions

The reference case market penetration of high-efficiency models for MFDs is from the Energy Star qualified product database, January 2004 (ICF 2004). In other cases, the reference case market penetrations are LBNL estimates based on the absence of power management features in these products prior to the initiation of the Energy Star program. Because power management features were uncommon before the Energy Star requirement, reference case penetrations for imaging products are generally low or zero. Aside from inkjet products, only MFD devices have non-zero reference case penetrations: 22% (office) and 50% (residential). The reference case market penetration for inkjet products is 50%. The free rider market penetrations are set equal to the reference case market penetration in all instances.

Because of the nature of the technology, inkjet devices typically meet the Energy Star level in their idle state without additional low power modes. Every unit in the LBNL (2000) printer sample met the Energy Star level in idle mode. For this reason, inkjet devices have no Energy Star savings.

We also model the following changes in the baseline:

- The percentage of devices left on for scanners, printers, and copiers was revised upward in 2003 based on Roberson et al. (2004). The result is an increase in the overall average REF UEC.

- For inkjet printers and scanners, the hourly energy use in modes changed in 2005 due to the implementation of the external power supply program. Lowering of the modal energies results in a decline in REF UEC.

- For color copiers, an increase in hourly energy in all modes is projected, equal to 1% per year increase.

- Between 1993 and 2004, low- and medium-speed monochrome copiers have declining hourly energy use. During the same period, high-speed copiers have increasing hourly energy use.

- For monochrome MFD and wide format printers, the baseline is constant.

Modeling Data for Calculating Energy Star Savings

Modeling data for imaging products comes from a variety of sources. The sources for hourly energy in operational modes are summarized in Table 6-40. The sources for time in mode are summarized in Table 6-41.

Table 6-40. Sources for energy use by imaging equipment

Product	REF	Energy Star
Monochrome copier	1993–2003: Nordman et al. (1998) 2004 and subsequent years *active* power from Star database January 2004 (Webber 2004)	1993–2006: *Active* mode same as REF; *standby* and *off* are averages from E* product database (STAR) February 2001 and January 2004 (Webber 2004) 2007 on: Total energy consumption (TEC) calculated from Energy Star criteria
Color copier	We do not have direct baseline estimates: *Active* mode 2006 estimates from LBNL metering of Energy Star units, *active* power is assumed to be the same for REF and Energy Star. *Standby* and *off* modes are the Energy Star values scaled by the ratio of the REF and Energy Star modal energies for mid-speed monochrome copiers. All other years are extrapolated with a 1%/yr increase.	2006 all modes from LBNL metering, other years extrapolated
Non-inkjet printer	LBNL metering, John Lee (Lee 1999)	LBNL metering, John Lee (Lee 1999) 2007 on TEC calculated from Energy Star criteria
Fax machine	LBNL metering 2000	*Active*, *standby*, and *off* from LBNL metering 2000, *Sleep* is Energy Star criterion
Non-inkjet MFD	Star Database January 2004 (Webber 2004)	1997–2006 Star Database (Webber 2001, 2004)
Inkjet printer	1993–2004 LBNL metering 2000 2005 onward reflect EPS program	*Active* and *standby* from LBNL metering 2000, 2005 data point is set to 8.9 W from Porter et al. 2006, 2007 Energy Star specification assumes active power reduced by same increment as ready If spec is greater than ready power, ready power is assumed. *Off* is Energy Star criterion.
Inkjet MFD	1993–2004 LBNL metering 2000 2005 onward reflect EPS program	*Active* assumed to be the same as REF. 1997–2005 *standby* is Energy Star criterion. Where sleep criterion is greater than REF it is set to REF. From 2007 on, *standby* is an Energy Star criterion, and *sleep* and *off* are set equal to *standby.*

Table 6-40, (Continued): Sources for energy use by imaging equipment

Product	REF	Energy Star
Inkjet fax	Assumed to be the same as inkjet printers	*Active*, *standby*, and *off* from LBNL metering 2000; *sleep* is Energy Star criterion
Scanner	LBNL metering 2000	LBNL metering 2000

Table 6-41. Sources for duty cycle by imaging equipment

Product	REF	Energy Star
Copier (mono and color)	Nordman et al. (1998)	Nordman et al. (1998)
Non-inkjet printer	Lee et al. (2000)	Lee et al. (2000)
Fax machine (both inkjet and not)	*Active* mode is an LBNL estimate, all other time is allocated to *ready*	*Active* is assumed to be the same as REF, *ready* is from Piette et al. (1995), *off* is the remainder
Non-inkjet MFD	*Active* mode is an LBNL estimate, all other time is allocated to *ready*	*Active* is assumed to be the same as REF, *ready* is from Piette et al. (1995), total *on* time is from Nordman et al. (1998), and *sleep* mode is *on* time less *active* and *ready*. *Off* time is *on* time subtracted from 24 hours.
Inkjet printer	Office: *Active* time is assumed to be the same as the lowest-speed laser printer, time in *ready* is the hours of operation from Piette et al. (1995). Residential: assumed to have the same times of operation as a laser printer.	*Active* is assumed to be the same as REF, *ready* is calculated as REF ready less E* sleep. Time in use is from Piette et al. (1995), *off* time is *on* time subtracted from 24 hours.
Inkjet MFD	Office: Time in active mode is an LBNL estimate; *ready* time is the hours of operation from Piette et al. (1995). *Off* is residual. Residential: assumed to be operated same as inkjet printers.	1997–2006 Energy Star qualified product database January 2004 (Webber 2001, 2004) 2007 *on* is same as REF, *ready* and total time in use are from Piette et al. (1995), and *sleep* is calculated as time in use less *active* and *ready*. *Off* is same as REF.
Scanner	*Off* mode is from LBNL metering 2000, time in active mode is an LBNL estimate, and *ready* is the calculated residual.	LBNL metering 2000

An example calculation of the Energy Star unit energy savings is presented in Table 6-42.

Table 6-42. Calculation methodology for imaging equipment

Office Inkjet 2008	Performance	REF	Energy Star
General Use	% Left On 24 hrs/day	70%	
	% in use/day	100%	
	Days in Use/yr	240	
	Hours of Use /day	9	
REF Case	Active/On (hrs/day)	12.8	
	Ready/Standby (hrs/day)	4.7	
	Sleep (hrs/day)	NA	
	Off (hrs/day)	1.8	
	Active/On (W)	0.08	
	Ready/Standby (W)	6.22	
	Sleep (W)	0.00	
	Off (W)	17.70	
	UEC turned off	22	
	UEC left on	41	
	Reference Case UEC	35	
Energy Star Case	Active/On (hrs/day)		0.08
	Ready/Standby (hrs/day)		5.00
	Sleep (hrs/day)		3.92
	Off (hrs/day)		15.00
	Active/On (W)		11.3
	Ready/Standby (W)		3.0
	Sleep (W)		3.0
	Active/On (hrs/day)		1.2
	Enabling Rate		95%
	Annual energy, turned off, enabled		14
	Annual energy, turned off, not enabled		14
	Annual energy, left on, enabled		26
	Annual energy, left on, not enabled		26
	Energy Star UEC		23

Note: Hours may not sum to 24 due to rounding.

6.10. Lighting

Product Category Description

The lighting category includes four Energy Star products: Energy Star fixtures, Energy Star decorative light strands (DLS), Energy Star exit signs, and Energy Star traffic signals. The lighting module begins in 1995 with the exit signs specification. Residential fixtures were added in 1998, followed by traffic signals (2000) and DLS (2008).

Energy Star Performance Criteria

Residential fixtures: See Energy Star Residential Fixtures specification available online at www.energystar.gov.

- Exit signs: The Energy Star exit signs program was terminated in 2006.
- DLS: Qualifying units must meet a 0.2 W per lamp power requirement.
- Traffic signals: The Energy Star traffic signals program was terminated in 2006.

Fixtures

The Energy Star Residential Light Fixture specification covers indoor and outdoor light fixtures, recessed down-light retrofit kits and replacement GU-24 base integrated lamps intended primarily for residential type applications. Our analysis covers the residential indoor and outdoor fixtures described below.

Unit Sales Data

Total U.S. sales data for indoor fixtures are from a variety of industry publications. Data on hardwired indoor fixture shipments for 1996–1998 are from U.S. DOC (1997). Portable fixture shipments are from the U.S. Lighting Fixtures Industry Volume 1 (1995/96 edition) (EIRI 1995). Shipments for 2000–2007 are from U.S. Census import data (U.S. DOC 2007) (we use the census data as a proxy for U.S. sales since most fixtures are imported). Total U.S. sales data for outdoor fixtures are from (U.S. DOC 1997). All other data are extrapolated. Total Energy Star sales data for both indoor and outdoor fixtures (2002–2007) are from manufacturer sales as reported to U.S. EPA by its partners (ICF 2003, 2004, 2006a, 2006b, 2007, 2008). All other years are extrapolated.

Key Baseline Assumptions

The reference case penetration for indoor fixtures is set to 1% in 1998 and is expected to increase throughout the forecast period at a rate of 0.02%. The 1998 estimate is based on Calwell and Granda (1999) and Calwell et al. (1999a, 1999b) analysis of fixtures that were able to qualify for Energy Star in its territory at the program launch. Our free ridership penetration is set to 50% of the reference case penetration.

The reference case penetration for outdoor fixtures is set at 2.5% and represents the fraction of units in the Tacoma Public Utilities dataset of metered fixtures that were able to qualify for the

Energy Star specification in 1998 (TPU 1996). We assume that this rate increases at 0.02% throughout the forecast period. Our free ridership penetration is set to 50% of the reference case penetration.

Modeling Data for Calculating Energy Star Savings

Savings for residential indoor fixtures are based on KEMA (2005), which reports power savings from incandescent/CFL lamp replacement for a sample of monitored fixtures in California homes. We assume replacement of a 65 W incandescent lamp with a 16 W compact fluorescent lamp and a daily operating time of three hours (KEMA 2005; Vine and Fielding 2006). We assume 1.64 lamps per fixture, based on the Tacoma Public Utilities study (TPU 1996).

Table 6-43. Data to support Unit Energy Savings (UES) for indoor fixtures in 2007

Original Wattage Incandescent	Typical CFL Replacement Wattage	CFL Wattage Assumed	Percent of Monitored Fixtures (%)
60	13–17	15	57
75	18–22	20	19
40	9–12	9	12
100	23–26	25	12
Average => 65		16	

Source: KEMA (2005)

Savings for outdoor fixtures assume replacing a 109 W incandescent lamp with a 36 W fluorescent lamp—or a savings reduction of two-thirds (Vorsatz et al. 1997). We assume a daily operating time of five hours (Vine and Fielding 2006).

The REF and Energy Star UECs are calculated according to Equation 5-10. The UES is calculated according to Equation 5-26 and Equation 5-28. Energy Star program savings are calculated according to Equation 4-1.

Decorative Light String (DLS)

A DLS is a string of lamps that operate on AC power in North America (120 V RMS AC, 60 Hz) or via a power adapter or controller that connects directly to AC power, and is used for decorative residential lighting purposes. The lamps may be replaceable or sealed into the lamp holder/wiring harness and may be assembled in a net or icicle configuration. We analyze two types of DLSs: mini-strings (100 lamps per string) and regular (25 lamps per string).

Unit Sales Data

Total U.S. sales data for DLSs in 2008 are from the U.S. Department of Census Import Data (we use import data as a proxy for U.S. sales since most products are imported). Sales for 2009–2025 are estimated to increase annually at a rate of 1.5%, which we estimated using the U.S. Census data (2000–2008) time series. Energy Star sales are LBNL estimates. Energy Star manufacturing partners began reporting sales to U.S. EPA in 2008 (U.S. DOC 2008).

Key Baseline Assumptions

Our reference case market penetration is estimated through personal communication with S. Altamura of Seasonal Specialties (Altamura 2006). Our reference case for both mini and regular DLS is 35% in 2008, with a one percentage point growth through 2025. LBNL estimates that 75% of units able to comply with Energy Star will participate in the program. Therefore, our free rider market penetration is set at 26% in 2008, with a one percentage point growth through 2025.

Modeling Data for Calculating Energy Star Savings

Our REF UEC is based on engineering data from Navigant Consulting (2006). The mini-string UEC is based on 0.42 W/lamp, 100 lamps/string, 10 hours per day, and 45 days per year. The regular-string UEC is based on 5 W/lamp, 25 lamps/string, 10 hours per day, and 45 days per year. The Energy Star UEC is based on the maximum power allowable under the specification (0.2 W per lamp). We use the same duty cycles as in our REF case.

The REF and Energy Star UECs are calculated according to Equation 5-10. The UES is calculated according to Equation 5-26, and Equation 5-28 Energy Star program savings are calculated according to Equation 4-1.

Exit Sign

An exit sign is a sign that is permanently fixed in place and used to identify a means of egress. An exit sign must have an illuminated, legally required legend**.** The Energy Star exit sign program was terminated in 2006 (with the implementation of a federal minimum efficiency standard), and Energy Star new sales do not accrue thereafter.

Unit Sales Data

One of the most uncertain aspects of this analysis is the number of exit signs sold in the United States each year and the relative breakdown of sales by technology (incandescent, CFL, or LED). We begin the analysis by setting total U.S. sales in 1994 equal to 1.2 million units (ESource 1994). We obtained a 2002 U.S. sales estimate from NEMA (Updyke 2003). All other data points are extrapolated. From 2003 to 2025, U.S. sale of exit signs is expected to increase at an annual rate of 1.2%, which equals the annualized growth in commercial floor space from U.S. DOE (1998). Total Energy Star sales data for exit signs (2002–2005) are from manufacturer sales as reported to U.S. EPA by its partners (ICF 2003, 2004, 2006a, 2006b).

Key Baseline Assumptions

To accurately model a baseline (and savings), we divided total U.S. sales data into four technology categories: incandescent, CFL, non-Energy Star LED, and Energy Star qualifying units. In 1995, approximately 45% of exit signs were incandescent, 40% were CFLs, 7.5% were non-Energy Star LED, and 7.5% were Energy Star LED (Suozzo and Nadel 1998). In 2002, we obtained technology market share data from NEMA and found that the breakdown was 7%

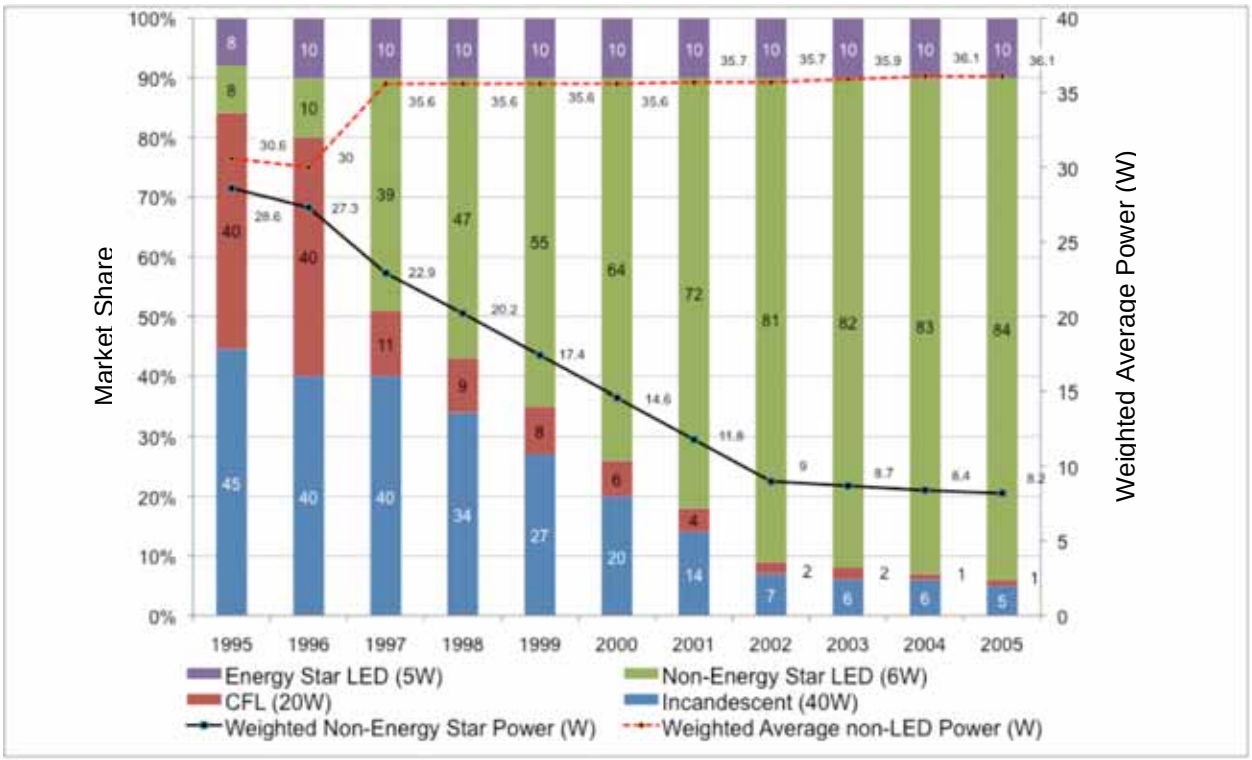
incandescent, 2% CFLs, 81% LED non-Energy Star LED, and 10% Energy Star units (Updyke 2003).

We use these data to establish a reference case market penetration, which we set equal to the market share of non-Energy Star LEDs and Energy Star qualifying units calculated from Suozzo and Nadel (1998) and NEMA (Updyke 2003). We discussed with NEMA whether or not these market trends were due to Energy Star. Based on this industry discussion, we determined that the market trends apparent in the data were not attributed to the program. In 1995, our reference case market penetration is 0%, and by 2002 it is 91%. Based on Energy Star unit sales data, of the efficient units (most of the market), few participate in the program. Our free rider market penetration is only 10%. The result of this is that our non-Energy Star UEC dramatically declines over time (250 kWh/yr in 1995 and 72 kWh/yr in 2005).

Modeling Data for Calculating Energy Star Savings

Savings for exit signs are based on Suozzo and Nadel (1998). Figure 6-2 shows applicable supporting data for our non-Energy Star UEC. We assume a duty cycle of 8,760 hours per year.

Figure 6-2. Data used in estimating Unit Energy Savings (UES) for exit signs



The REF and Energy Star UECs are calculated according to Equation 5-12. The UES is calculated according to Equation 5-26 and Equation 5-28. Energy Star program savings are calculated according to Equation 4-1.

Traffic signal

Our analysis includes red and green traffic signals. We do not consider yellow traffic signals.

Unit Sales Data

In the case of traffic signals, we do not collect U.S. sales data due to issues with data availability and time-series consistency. Instead, we operate directly off of the Energy Star unit sales data. Total Energy Star sales data for traffic signals (2002–2005) are from manufacturer sales as reported to U.S. EPA by its partners (ICF 2003, 2004, 2006a, 2006b). All other years are extrapolated.

Key Baseline Assumptions

Our reference case penetration is based on Suozzo (1998) and assumes a 4% penetration in 2000, increasing to 10% in 2005. Participation in the traffic signal program was historically low, and our best estimate is that free ridership was only about 1% of total Energy Star traffic signal sales. A federal minimum efficiency standard was introduced in 2006, and no savings from new sales accrue thereafter.

Modeling Data for Calculating Energy Star Savings

Our REF wattage and duty cycle assumptions are engineering data from Durgin (1999) and Suozzo (1998), and these are shown in the following tables. Red signals include 12″ red balls, 8″ red balls, 12″ red arrows, pedestrian hands, and a pedestrian walking man. Green signals include 12″ green balls, 8″ green balls, and 12″ green arrows. We use the estimated stock of traffic signals by type to create a weighted average red and green wattage and duty factor. Duty cycle factors are based on 8,760 hours per year.

Table 6-44. Traffic signal wattages, average duty cycle, and installed stock

Traffic Light Type	REF (W)	Energy Star (W)	On Time (%)	Stock Units (circa year 2000)
12" red ball	150	11	55	1,690,000
8" red ball	67	8	55	910,000
12" red arrow	150	9	90	650,000
12" green ball	150	15	42	1,300,000
8" green ball	67	12	42	1,300,000
12" green arrow	150	11	10	650,000
ped hand	67	13	90	1,170,000
ped walking man	67	9	10	1,170,000

Source: Suozzo 1998; Durgin 1999 for REF. Energy Star is based on the specification.

The REF and Energy Star UECs are calculated according to Equation 5-24. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

6.11. Roofing

Product Category Description

Roofing consists of two products: low-slope roof products and steep-slope roof products. Our analysis includes residential roofs (steep-slope) and commercial roofs (low-slope). The roofing module begins in 1999.

Energy Star Performance Criteria

Residential roofing:

- Initial solar reflectance greater than or equal to 0.25
- Maintenance of solar reflectance greater than or equal to 0.15 three years after installation under normal conditions

Commercial roofing:

- Initial solar reflectance greater than or equal to 0.65
- Maintenance of solar reflectance greater than or equal to 0.5 three years after installation under normal conditions

Residential roofing covers steep-slope roofs. Commercial roofing covers low-slope roofs.

U.S. Sales

Total U.S. sales data for residential and commercial roofing are from a variety of industry sources. Our 1996 estimate is from Freedonia (1997) and our 2002 estimate is from the National Roofing Contractors Association (NRCA 2003). All other years are extrapolated. Total Energy Star sales data for residential roofing (2002–2007) are from manufacturer sales as reported to U.S. EPA by its partners (ICF 2003, 2004, 2006a, 2006b, 2007, 2008). All other years are extrapolated. All sales data are expressed in billion square feet of roofing.

Key Baseline Assumptions

Residential:
The reference case penetration for residential roofing is set to 2%. This estimate is derived from conversations with various manufacturers. We estimate that prior to the Energy Star program roughly 5% of all roofs being sold were reflective. We assume that of the 5% reflective sales, approximately 20% was sold to the residential sector. Our free rider market penetration is set to half of the reference case market penetration, based on estimates of Energy Star unit sales during the early years of the program. Our reference case and free rider market penetration is held constant over time.

In addition to accounting for free riders, we also factor into our model the sales that are due to the Energy Star new homes program such that the Homes Program gets first claim on all sales

above the free rider level and the Energy Star Product Labeling Program is credited with whatever sales remain.

Commercial:
The reference case penetration for commercial roofing is set to 9%. This estimate is derived from conversations with various manufacturers. We estimate that prior to the Energy Star program roughly 5% of all roofs being sold were reflective. We assume that of the 5% reflective sales, approximately 80% were sold to the commercial sector. Our free rider market penetration is set to 0.05% of all sales based on estimates of Energy Star unit sales during the early years of the program. Our reference case and free rider market penetration is held constant over time.

Modeling Data for Calculating Energy Star Savings

We do not have UECs in the roofing module. Instead, an Energy Star UES for reflective roofing is taken directly from building simulation results reported in Konopacki et al. (1997). The UES includes two components: savings from electric cooling and a heating penalty (weighted by the fraction of residential homes using electric versus gas heating). These estimates are shown below in Table 6-45. Our UES is held constant over time.

Table 6-45. Energy Star UES for residential roofing in 2007

Sector	Cooling Savings (kWh/1000 ft^2)	Gas Heating Increase (MBtu/1000 ft^2)	Electric Heating Increase (kWh/1000 ft^2)	Gas Share (%)	Electric Share (%)
Residential	175	-0.58	-170	76	24
Commercial	273	-0.6	-176	75	25

Energy Star program savings are calculated according to Equation 4-1.

6.12. Set-Top Box (STB)

Product Category Description

Digital set-top box (STB) is general term to cover a consumer electronic device that receives and decodes digital video signals from one or any combination of satellite, cable, terrestrial, and/or Internet protocol (IP) service and presents the decoded video to a display and/or recording device via one or more analog and/or digital interfaces for consumption by an end user. We include cable, IP, satellite, and terrestrial (digital television adapters or DTAs) in our analysis.

Energy Star Performance Criteria

- Cable, satellite, IP, terrestrial: Version 1.0 was a mode-based specification that was launched in 2001 and suspended in 2005. Version 2.0 was effective in 2009 and includes a total energy consumption-based energy performance criteria, as well as requirements for service providers. See Table 6-46 and Table 6-47.
- DTA: *Active* mode < 8 W; *sleep* mode < 1 W

Table 6-46. Energy Star version 2.0 criteria for STB base functionality

Base Functionality	Tier 1 Annual Energy Allowance (kWh/year)	Tier 2 Annual Energy Allowance (kWh/year)
Cable	70	50
Satellite	88	56
IP	45	36

Note: Tier 1 is effective during 2009–2010, and Tier 2 is 2011 onward.

Energy Star criteria also include allowances for added functionality, as shown in Table 6-47.

Table 6-47. Energy Star version 2.0 criteria for STB additional functionalities

Additional Functionalities	Tier 1 Annual Energy Allowance (kWh/year)	Tier 2 Annual Energy Allowance (kWh/year)
Additional Tuners	53	16
Additional Tuners – Terrestrial /IP	14	8
Adv. Video Processing	18	12
DVR	60	32
High Definition	35	12
Removable Media Player	12	8
Removable Media Player/Recorder	23	10
Multi-Room	44	25
CableCARD	15	TBD
DOCSIS	20	TBD
Home Network Interface	20	10

Note: Tier 1 is effective during 2009–2010, and Tier 2 is 2011 onward.

Cable Box

Cable is a STB whose principal function is to receive television signals from a broadband, hybrid fiber/coaxial, community cable distribution system and deliver them to a consumer display and/or recording device.

Unit Sales Data

Total U.S. sales data are from two sources. For 2000–2004, shipments were set at a level to equal a stock of 42 million units in 2006 (assuming a 7-year lifetime) as reported in Roth and McKenney (2007). U.S. sales for 2005–2011 are from Paxton (2007) and Abraham (2008) industry report for cable boxes. Our growth rate is based on Paxton (2007), which shows flat unit shipments 2008–2011, so we assume a 0% growth rate as IP boxes increase in market penetration and offset cable box shipments.

We have partner-reported Energy Star sales data for 2003 and 2004. All other years are extrapolated. Version 2.0 is effective beginning in 2009. Once effective, Energy Star unit sales data will be collected. Currently, we are estimating Energy Star sales by considering the fleet

size of service providers and the likelihood of the provider participating in the program based on U.S. EPA feedback. We use the average likelihood of joining and multiply that estimate by 0.5 (the Energy Star service provider requirement is that 50% of new sales must be qualified units) to get an average market penetration and hold this constant over time (Beavers 2007).

Key Baseline Assumptions

The reference case market penetration is set to 0% and is held constant over time (a lack of service provider participation prior to Energy Star prevented boxes from meeting criteria while in operation). The reference case penetration is based on industry feedback during the specification development process.

Modeling Data for Calculating Energy Star Savings

Version 1.0 REF *on* and *standby* mode power consumption is based on LBNL measured data collected in 1999 and measured data from Roth and McKenney (2007). Energy Star standby power is set to the maximum allowable under the Version 1.0 specification. Usage patterns are measured duty cycles taken from Porter et al. (2006). Version 2.0 is calculated as total annual energy consumption and factors in unit features with functional adders such as high definition features, tuners, and digital video recorders. Both the REF and Energy Star UEC is an engineering estimate based on manufacturer data (Beavers 2007). The Energy Star UEC assumes the maximum allowable consumption under the specification.

Table 6-48. REF and Energy Star UEC for cable boxes in 2009

	REF	Energy Star Tier 1	Energy Star Tier 2
Annual Energy Consumption (kWh/yr)	250	173	85

Note: The UEC represents a weighted average of tuner-only units, tuner with HD, DVR, and DVR with HD. We assume a 25% market share for each type.

Satellite

A satellite box is a STB whose principal function is to receive television signals from satellites and deliver them to a consumer display and/or recording device.

Unit Sales Data

Total U.S. sales data are from two industry sources. Sales for 1999–2001 are from *Appliance Magazine's* Statistical Review, 53rd annual report, 2006. Sales for 2002–2007 are from the Consumer Electronics Sales & Forecasts 2002–2007 (CEA 2006). *Appliance Magazine* and CEA data show a declining sales volume, so we assume a 0% growth rate.

The only year where there were Energy Star sales for satellite boxes was 2003 (ICF 2004). Version 2.0 is effective beginning in 2009. Once effective, Energy Star unit sales data will be collected. Currently, we are estimating Energy Star sales by considering the fleet size of service providers and the likelihood of the provider participating in the program based on U.S. EPA

feedback. We use the average likelihood of joining and multiply that estimate by 0.5 (the Energy Star service provider requirement is that 50% of new sales must be qualified units) to get an average market penetration and hold this constant over time (Beavers 2007).

Key Baseline Assumptions

The reference case market penetration is set to 0% and is held constant over time (a lack of service provider participation prior to Energy Star prevented boxes from meeting criteria while in operation).

Modeling Data for Calculating Energy Star Savings

Version 1.0 REF *on* and *standby* mode power consumption is based on LBNL measured data collected in 1999 and measured data from Roth and McKenney (2007). Energy Star standby power is set to the maximum allowable under the Version 1.0 specification. Usage patterns are measured duty cycles taken from Porter et al. (2006).

Version 2.0 is calculated as total annual energy consumption and factors in unit features with functional adders such as high-definition features, tuners, and digital video recorders. Both the REF and Energy Star UEC are engineering estimates based on manufacturer data from Cadmus group (Beavers 2007). The Energy Star UEC assumes the maximum allowable consumption under the specification.

Table 6-49. REF and Energy Star UEC for satellite boxes in 2009

	REF	Energy Star Tier 1	Energy Star Tier 2
Annual Energy Consumption (kWh/yr)	247	178	98

Notes: The UEC represents a weighted average of tuner-only units, tuner with HD, DVR, and DVR with HD. We assume a 25% market share for each type.

Internet Protocol (IP)

An IP box is a STB whose principal function is to receive television/video signals encapsulated in IP packets and deliver them to a consumer display and/or recording device.

Unit Sales Data

Total U.S. sales data are from In-Stat (2008) for 2005–2012. We do not include IP boxes in our forecast until the Version 2.0 specification, so partner-reported Energy Star sales are not relevant. We assume a 1.9% growth rate for 2013–2025 based on Paxton (2007) and Abraham (2008) shipment trends.

Currently, we are estimating Energy Star sales by considering the fleet size of service providers and the likelihood of the provider participating in the program based on U.S. EPA feedback. We use the average likelihood of joining and multiply that estimate by 0.5 (the Energy Star service

provider requirement is that 50% of new sales must be qualified units) to get an average market penetration and hold this constant over time.

Key Baseline Assumptions

The reference case market penetration is set to 0% and is held constant over time (a lack of service provider participation prior to Energy Star prevented boxes from meeting criteria while in operation).

Modeling Data for Calculating Energy Star Savings

IP boxes are only effective under Version 2.0. Version 2.0 is calculated as total annual energy consumption and factors in unit features with functional adders such as high definition features, tuners, and digital video recorders. Both the REF and Energy Star UEC are engineering estimates based on manufacturer data from Cadmus Group (Beavers 2007). The Energy Star UEC assumes the maximum allowable consumption under the specification.

Table 6-50. REF and Energy Star UEC for IP boxes in 2009

	REF	Energy Star Tier 1	Energy Star Tier 2
Annual Energy Consumption (kWh/yr)	185	112	69

Note: The UEC represents a weighted average of tuner-only units, tuner with HD, DVR, and DVR with HD. We assume a 25% market share for each type.

Terrestrial (DTA)

A digital television adpapter (DTA) is a STB that receives terrestrial (over the air, or OTA) digital signals and converts them to an analog output suitable for analog televisions. A DTA does not provide digital signal output.

Unit Sales Data

As of December 2006, CEA estimates a total of 36.7 million OTA televisions in the United States. Due to the natural product replacement cycle, CEA estimated that there would be ~25 million OTA sets in the United States at the time of the 2009 digital conversion. We assume all DTAs will be shipped in 2009. Energy Star sales are estimates, and we assume 25% of the market, or about 6 million units.

Key Baseline Assumptions

The reference case market penetration is set to 0% and is held constant over time (based on industry feedback during specification development process). The REF is set to the National Telecommunications and Information Administration (NTIA) federal standard of 2 W in *standby* mode.

Modeling Data for Calculating Energy Star Savings

Our UEC includes three modes: *on, sleep,* and *standby.* Our REF *on* power is 17 W taken from an American Council for an Energy-Efficient Economy (ACEEE) report (Thorne Amann 2004) and *sleep* power is set to the NTIA standard of 2 W. The *on* mode usage pattern reflects a daily usage estimate and an assumption that a unit is used 351 days per year. We assume the DTA is on 5 hours per day for TV viewing (Roth and McKenney 2007), which is divided into two viewing periods per day. The NTIA standard requires the device to enter *sleep* mode after a four-hour power-down period. With two viewing periods per day, total power-down hours equals 8 per day. We sum viewing hours and power-down hours to calculate the total hours in *on* mode (13 hours per day). *Sleep* mode hours is simply 24 minus 13, or 11 hours per day (assuming the equipment is not manually turned off). Energy Star *on* power is set to the maximum power allowable under the specification (8 W) and the *standby* mode is set to the maximum power allowable under the specification (1 W). The Energy Star and REF usage pattern are equivalent.

To calculate a UEC, we factor in a power management enabling rate (the success rate of entering *sleep/standby* mode through the auto power-down feature), which is defined as the percentage of all units that are power-managing successfully in a given year (we set this equal to 80%). We also factor in equipment turn-off rates (50%). Enabling and turn-off rates are taken from NYSERDA 2006.

Table 6-51. REF and Energy Star UEC for DTAs in 2009

	REF	Energy Star
Annual Energy Consumption (kWh/yr)	71	34

The REF and Energy Star UEC are calculated using Equation 5-1 through Equation 5-3. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

6.13. Small appliances

Product Category Description

Energy Star small appliances include dehumidifiers, air cleaners, ventilation fans, and ceiling fans.

Dehumidifiers are a single product type, but in the analysis they are divided into six capacity bins. The bins are based on the number of pints of water removed from the air daily. Reference case and Energy Star dehumidifier criteria are listed in Table 6-52.

The Energy Star specification for room air cleaners was initiated in July 2004. The room air cleaner minimum performance requirement is based on Clean Air Delivery Rate (CADR). Qualifying units must achieve at least 2.0 CADR/Watt under specified test procedures. See Table 6-53.

Ventilation fans may qualify for the Energy Star label by meeting efficiency requirements for the fan, expressed as cubic feet per minute per watt (cfm/W), and lighting source requirements. The latter includes minimum requirements for lumens per watt and non-energy factors such as start time, color rendering, noise, and lamp lifetime. See Table 6-54 and Table 6-55.

Ceiling fan models can qualify for the Energy Star label by meeting minimum airflow and lighting efficiency requirements. These requirements are summarized in Table 6-56 and Table 6-57.

Energy Star Performance Criteria

The Energy Star performance criteria for dehumidifiers, air cleaners, ventilation fans and ceiling fans are presented below.

Table 6-52. REF and Energy Star criteria for dehumidifiers in 2008 and 2015

Bin	Nominal Capacity (Pint/day)	Capacity (Pint/day)	2008 Energy Star	2008 REF	2013 REF
1	> 25	10.6	1.2	1.1	1.35
2	25–35	14.2	1.4	1.2	1.4
3	35–45	18.9	1.5	1.3	1.5
4	45–54	23.4	1.6	1.3	1.6
5	54–75	30.5	1.6	1.5	1.7
6	75–185	43.9	2.5	2.25	2.5

Notes:
- The capacity estimates for bins 1 and 6 are average values from the Energy Star product list, the capacities for bins 2 through 5 are the mid-points of the bins.
- The initial baseline energy factors (EFs) are from CSA data, with the exception of bin 5, which is based on LBNL judgment. 2008 and 2013 baseline EF are set to Energy Policy Act of 2005 (EPAct) federal levels.
- Effective in October 2007, the requirement for 75-pint models was moved to the next largest capacity bin for qualification. This means they will need to have an energy factor of > 2.50.
- Effective June 2008, the requirement for products with a capacity of > 54 to < 75 pints/day was increased to an energy factor of > 1.80 liters per kilowatthour (L/kWh).
- For bin 1 and 3 in the 2013 reference case, EF is equal to Energy Star, so there are no Energy Star savings for those types after 2012.

Table 6-53. Reference Case and Energy Star UEC for air cleaners in 2007

Nominal CADR	Ave. CADR	Reference Case		Energy Star	
		Watts	UEC (kWh/yr)	Watts	UEC (kWh/yr)
0–50	16.7	29	250	8	73
51–100	73.5	68	596	37	322
101–150	118.5	122	1,072	59	519
151–200	172.6	169	1,480	86	756
201–250	226.7	215	1,887	113	993
Over 250	285.6	187	1,641	143	1,251

Table 6-54. Reference Case and Energy Star ventilation fan efficiencies in 2007

Fan type	Reference case (cfm/W)	Energy Star Criterion (cfm/W)
1–80 CFM	0.4	1.4
> 80 CFM	0.87	2.8
Range hood	0.85	2.8

Table 6-55. Energy Star ventilation fan lamp efficiency criteria

Lamp type (W and tube length)	Criterion (lm/W)
< 30 W	46
> 30 W and < 24″ in length	60
> 30 W and > 24″ in length	70

Table 6-56. Energy Star ceiling fan lamp efficiency criteria

Lamp type	Criterion
< 30 W	50
> 30 and < 24″	60
> 30 and > 24″	70

Table 6-57. Reference Case and Energy Star UECs for ceiling fans in 2007

Type	Reference Case 2002–2005 (kWh/yr)	Reference Case 2006–2025 (kWh/yr)	Energy Star (kWh/yr)
Fan only South region	114	114	104
Fan only	40	40	37
Fan w/ light South region	309	177	169
Fan w/ light	284	120	117
Lighting kit	227	75	75

Note: Fan consumption is distinguished by region due to higher operating hours in warmer climates.

Dehumidifier

A dehumidifier is a self-contained, electrically operated, and mechanically refrigerated encased assembly consisting of an evaporator that condenses moisture from the atmosphere; a refrigerating system; an air-circulating fan; and means for collecting and/or disposing of the condensate.

Unit Sales Data

U.S. shipments in 1996–2005 are from *Appliance Magazine's* "Statistical Review 53rd Annual Report" (Appliance Magazine 2006). Shipments in 2006 are from Appliance Magazine's 54th Annual Appliance Industry Forecast (Appliance Magazine 2007b). Shipments after 2006 are

extrapolated using an estimate of 2% growth per year based on apparent growth 1991–2001 from the Association of Home Appliance Manufacturers (AHAM) (2000).

Energy Star shipments in 2002 are from the Energy Star Market Penetration Report Calendar Year 2002 (ICF 2003); in 2003 manufacturer-reported data, and 2004–2007 on are from the Energy Star Unit Shipment Data Reports, ICF Consulting (ICF 2004, 2006a, 2006b, 2007, 2008). Future shipments are forecast from the 2007 figure, assuming 1% per year growth.

Key Baseline Assumptions

The baseline market penetration of high-efficiency units is initially set to 25% and declining to 10% in 2006 due to the specification revision. Baseline penetrations are based on U.S. EPA comments in its Version 1.0 specification. Free riders are set to 10% in 2001–2005, declining to 5% in 2006, and set to zero subsequently. We also model declines in the REF UEC in 2007, and in 2013 due to federal standard being implemented. The 2013 federal standard exceeds the Energy Star standard, so there are no savings from that point on.

Modeling Data for Calculating Energy Star Savings

The unit energy consumption is calculated using an annual usage estimate of 1620 hours based on Cadmus (1999c). The Energy Star annual hours of use is the same as the reference case, with the exception of high-capacity units, i.e., bins 5 and 6. In those cases a run time of 360 hours per month is used, based on Zogg and Alberino (1998). We assume year-round use for high-capacity units, since they are sized for intensive moisture problems.

The initial REF energy factor is from the Canadian Standards Association; the 2007 and 2013 energy factors are the federal EPAct levels. The energy factors for the Energy Star UEC are from the Energy Star specification. After 2013 the Energy Star UEC is set equal to REF, as the federal standard is more stringent.

The REF UEC and Energy Star UEC are calculated by Equation 5-11, the non-Energy Star UEC is calculated by Equation 5-28, and Energy Star program savings are calculated by Equation 4-2.

Air Cleaners

Room air cleaners are electric cord-connected, portable appliances with the primary function of removing particulate matter from the air and which can be moved from room to room. Air cleaners are a single product; in the analysis they are divided in to 5 bins, based on CADR.

Unit Sales Data

U.S. shipments are based on the ICF market assessment, which provided shipment data for 1995 through 2006. LBNL had to adjust the breakdown in 2006 to account for high Energy Star shipments in certain CADR areas. Shipments of Energy Star units 2005–2007 are from the Energy Star annual shipment report compiled by ICF; subsequent years are LBNL estimates.

Key Baseline Assumptions

The average baseline market penetration is 15% in 2004 but varies among the bins and over time; the penetration rates range from 10% to 40%. Free rider market share is lower than the baseline share, so the non-Energy Star UEC is lower than the reference case UEC.

We do not model any changes to the baseline energy consumptions.

Modeling Data for Calculating Energy Star Savings

The Baseline and Energy Star UECs are based on wattage estimates from AHAM in 2003. Units are assumed to be in continuous use all year. The Energy Star UEC is based on the average CADR for the bin and the Energy Star criterion of 2 CADR/ watt.

The REF UEC and Energy Star UEC are calculated by Equation 5-23, and the non-Energy Star UEC by Equation 5-28. Energy Star program savings are calculated by Equation 4-1.

Ventilation Fans

A ventilation fan is a ceiling-mounted, wall-mounted, or remotely mounted in-line fan designed to be used in a bathroom or utility room, or in a kitchen range hood, whose purpose is to move objectionable air from inside the building to the outdoors. Ventilation fans are divided into exhaust fans low (1–80 cfm), exhaust fans high (> 80 cfm), exhaust fan lighting, range hood fan, and range hood fan lighting.

Unit Sales Data

The initial stock of installed units is set equal to the annual shipments times the number of years in a unit lifetime. Initial U. S. shipments are based on Cadmus (1999e). Shipment growth is assumed to be the same as the growth rate of the AEO housing stock: 1.03%. Total shipments are disaggregated into bins based on analysis by LBNL (Roberson 2001).

Shipments of Energy Star units 2002–2007 are from the Energy Star annual shipment reports compiled by ICF (2003, 2004, 2006b, 2007).

Key Baseline Assumptions

The reference case market penetration of high-efficiency exhaust fans is from analysis by LBNL (Roberson 2001). The initial reference case market penetration is 1.8% for low flow and 4.7% for high flow, and the estimate of the penetration rate rises gradually throughout the forecast period, reaching 13% and 28% respectively in 2025. The reference case market penetration of high-efficiency rangehoods is set to zero, based on the percentage of fans with split capacitor motors before the onset of the program. For fan lighting, the initial reference case market penetration is 30% and is constant over time, based again on the LBNL analysis (Roberson 2001). The reference case penetration rate for rangehood lighting is 6.3% and is also constant,

this estimate is the percentage of rangehoods with CFL lamps from the Tacoma Public Utility (TPU) dataset (Tribwell 1997).

The market penetration rate of free riders among exhaust fans is from Cadmus (1999e), and is equal to the reference case market penetration. The free riders penetration rate for exhaust fan lighting is initially zero, is set to 0.5% in 2006, and gradually rises to 10% in 2025. For rangehood fans, the reference case market penetration is zero, so there are no free riders. Exhaust fan and rangehood lighting both have a higher reference case than free rider penetration rates, meaning that there are high-efficiency models on the market that do not participate in the program. For these products, the non-Energy Star UEC is lower than the reference case UEC.

Modeling Data for Calculating Energy Star Savings

The reference case UEC is from LBNL analysis (Roberson 2001). In the UEC calculation, usage is modeled as 1 hour a day, 350 days per year. The airflow and efficiency varies between the two airflow capacity types.

The reference case UECs for exhaust fan and rangehood lighting are from the TPU dataset, and are averages. The Energy Star UECs are calculated from the reference cases, assuming a 67% improvement in lighting efficiency.

Ceiling Fans

An Energy Star ceiling fan is a device intended for circulating air in a home via the rotation of fan blades that is suspended from the ceiling. Some ceiling fans also have an integral or attachable light kit. Because the use of ceiling fans varies according to climate, they are divided in the model into two regions, based on census divisions: South, and the rest of the country. Units with lights are modeled separately from fan-only units, as are stand-alone light kits.

Unit Sales Data

The initial stock of installed units is from Calwell and Horowitz (2001). This is a national estimate which was disaggregated to regions using percentages of homes with fans from the *Residential Energy Consumption Survey* (RECS) 2001 (U.S. DOE 2004) and to fan-only and lighted types using estimates from (Robinson 2005).

U.S. shipments come from *Appliance Magazine* publications 1978–1995 and from Appliance 51th Annual Report (May 2003) and Appliance 48th Annual Report (May 2000); Shipments 1996–2005 from Appliance Magazine Statistical Review 53rd Annual Report, 2006; and 2006 from 55th Appliance Industry Forecast from Appliance Magazine 2006. Years after 2007 are extrapolated using the 1984–2007 average growth rate of 8%. Shipments were disaggregated using the same method as the stock estimate. Shipments of Energy Star units are from the Energy Star annual shipment reports (ICF 2004, 2006a, 2006b, 2007, 2008).

Key Baseline Assumptions

The initial reference case market penetration of high-efficiency fan-only units is based on product metering by Ecos Consulting (Calwell and Horowitz, 2001). For fans with lights, the initial reference case market penetration is based on Energy Star shipment data from the ICF Market penetration report for the calendar year 2003. A 1% per year increase in the penetration rates for units with and without fans is modeled.

For ceiling fans without lights, the free rider market penetration is set to 90% of the reference case market penetration. This means that there are high-efficiency models on the market that do not participate in the Energy Star program, therefore the non-Energy Star UEC is lower than the Energy Star UEC for this product type. The free rider market penetration rate for ceiling fans with lights is set equal to the reference case market penetration, meaning that all models that could qualify for the label do participate in the program. The Energy Star program is not credited with savings for these models.

Modeling Data for Calculating Energy Star Savings

The reference case and Energy Star UECs are based on usage patterns from Calwell and Horowitz (2001), updated to the numbers of homes in U.S. DOE (2004). Regional estimates of the numbers of fans and hours of use per day are combined with the reference case and Energy Star efficiencies to obtain the respective UECs. The reference case energy use by lighting is based on the same times of use as fans and an assumption that the fan lighting units utilize three 60-watt lamps. The Energy Star lighting UEC is based on the reference case UEC and an assumption of 67% savings. Starting in 2006, the reference case is assumed to use CFLs for lighting, therefore, and the lighting UEC is equal to the Energy Star UEC.

6.14. Telephony

Product Category Description

Energy Star Telephony includes additional handsets, cordless phones (analog and digital spread spectrum, or DSS, analyzed separately), answering machines, and combination phones (analog and DSS analyzed separately). Energy Star Telephony was launched in 2002.

Energy Star Performance Criteria

Energy Star-qualified telephony equipment is required to meet the criteria shown in Table 6-58.

Table 6-58. Energy Star version 2.0 telephony criteria

Product Category	**Version 2.0 Requirements** Effective November 1, 2006
• Additional Handset	≤ 1 watt
• Answering Machine • Cordless Telephone • Multi-Handset Cordless Telephone	≤ 2 watts
• Answering Machine with SST • Cordless Telephone with SST • Multi-Handset Cordless Telephone with SST	≤ 2 watts
• Combination Cordless Telephone/Answering Machine • Multi-Handset Combination Cordless Telephone/Answering Machine	≤ 2.5 watts
• Combination Cordless Telephone/ Answering Machine with SST • Multi-Handset Combination Cordless Telephone/Answering Machine with SST	≤ 2.5 watts

Energy Star-qualified units must be equipped with an Energy Star external power supply when present.

The methodology and data sources for calculating Energy Star telephony savings are consistent across all product categories that we cover. For this reason, we present an overview that is applicable across all product categories.

Unit Sales Data

Total U.S. sales data (2000–2007) are from the Consumer Electronics Association Market Research Department (CEA 2000, 2001a, 2001b, 2002, 2005, 2007a, 2007b).

For all product categories other than additional handsets, we have partner-reported Energy Star sales for 2004–2007 (ICF 2006a, 2006b, 2007, 2008). We have partner-reported Energy Star sales of additional handsets for 2007 only (ICF 2008). All other years are extrapolated.

Key Baseline Assumptions

The reference case market penetration is based on metering conducted by LBNL and Florida Solar Energy Center in 1997, 1998, and 2003. Reference case penetrations in 2002 are:

- Answering machines: 60%
- Cordless phones: 55%
- DSS cordless phones: 55%
- Combination phones: 40%
- DSS combination phones: 40%
- Additional handsets: 0%

The Energy Star sales data shows that the number of units that actually participate in the program is much less than the number of units that were able to qualify (based on the test data). As a result, the free rider penetration was set to the ratio of Energy Star unit sales/total U.S. sales in the first year of the program. The free rider penetrations are listed below:

- Answering machines: 0% (no Energy Star sales have ever been reported for the program)
- Cordless phones: 25%
- DSS cordless phones: 25%
- Combination phones: 40%
- DSS combination phones: 30%
- Additional handsets: 0%

Beginning in 2006 (the Tier 2 requirements effective year), the reference case and free rider penetration is 0%, since no metered products were able to comply with the criteria at the time of the initial specification launch. Our REF is modeled to reflect improvements in external power supply efficiency that resulted from the Energy Star external power specification and the federal minimum efficiency standard. These effects result in a REF reduction in 2005 and again in 2009.

Modeling Data for Calculating Energy Star Savings

The UEC reflects four power-consuming modes: *active, charge (empty battery), charge (full battery), and standby.* REF power consumption is measured data taken from Rosen et al. 2001 and measured data by FSEC, LBNL, and UC Berkeley (Webber 2003). The Energy Star *standby* power consumption is set to the maximum allowable consumption. Savings for *charge* mode and *active* mode reflect power reductions due to an improved power supply efficiency that is required by the Energy Star specification. Usage patterns are estimates taken from Rosen et al. 2001.

The REF and Energy Star UECs are calculated according to Equation 5-1. The UES is calculated according to Equation 5-26 and Equation 5-28**.** Energy Star program savings are calculated according to Equation 4-2.

6.15. Transformers

Product Category Description

Transformers include two categories: commercial and industrial (C&I) transformers and utility transformers.

Energy Star Performance Criteria

- Energy Star C&I transformers was terminated in 2007
- Energy Star Utility transformers was terminated in 2002

Transformers cover C& I and utility transformers.

Unit Sales Data

Commercial & Industrial:
U.S. sales were 243,000 units in 1998 (ORNL 1996). The growth rate through 2025 is estimated at 1.2% (ORNL 1996). Energy Star unit sales (2003–2006) are manufacturer sales as reported to U.S. EPA by its partners (ICF 2004, 2006a, 2006b, 2007, 2008). All other years are extrapolated.

Utility:
U.S. sales are set at 1.1 million units in 1995 (ORNL 1996). The growth rate through 2025 is estimated at 2% (ORNL 1996). Energy Star unit sales (1995–2001) are U.S. EPA estimates. Utility transformers were removed from the program in 2002. Savings from new sales do not accrue after 2001.[4]

Key Baseline Assumptions

Commercial & Industrial:
The reference case penetration for C&I transformers is set to 6% in 1995 and is held constant through 2005 (ORNL 1996). We estimate that the free rider market penetration is also 6%, meaning that all units that were able to qualify for Energy Star transformers in 1995 also participated in the program. In 2006, the federal minimum efficiency standard became effective. The federal level was set equivalent to the Energy Star performance level and savings do not accrue beginning in 2006 for new sales.

Utility:
The reference case penetration for utility transformers is set to 10% in 1995 and is held constant through 2005 (ORNL 1996). We estimate that the free rider market penetration is also 10%, meaning that all units that were able to qualify for Energy Star transformers in 1995 also participated in the program. The free rider market penetration is also held constant through 2002, when the program was terminated.

Modeling Data for Calculating Energy Star Savings

Commercial & Industrial:
Our REF UEC is based on a transformer with an average 45 kW rating, an average efficiency of 97.29%, a loss multiplier of 1.1, and an average load factor 35% (Suozzo and Nadel 1998). In 2006, our REF is set equal to the Energy Star efficiency level due to the federal standard. The average Energy Star efficiency is set at 98%.

Utility:
Our REF UEC is based on a transformer with an average 25 kW rating, an average efficiency of 98.5%, a loss multiplier of 1.1, and an average load factor 30% (Suozzo and Nadel 1998). The average Energy Star efficiency is set at 98.6%. Table 6-59 shows inputs to our UEC.

[4] The transformer specification was not terminated until 2007. Utility transformers were removed in 2002 and only C&I transformers were included in the program from 2002–2006.

Table 6-59. Inputs to UEC for C&I and utility transformers in 2007

Performance	C&I		Utility	
	REF	Energy Star	REF	Energy Star
Rating (kW)	45	45	25	25
Load factor	0.35	0.35	0.30	0.30
Efficiency	97%	98%	98.5%	98.6%
Duty cycle (hrs/yr)	8,760	8,760	8,760	8,760
Loss multiplier	110%	110%	110%	110%

The REF and Energy Star UECs are calculated according to Equation 5-25. The UES is calculated according to Equation 5-26 and Equation 5-27. Energy Star program savings are calculated according to Equation 4-1.

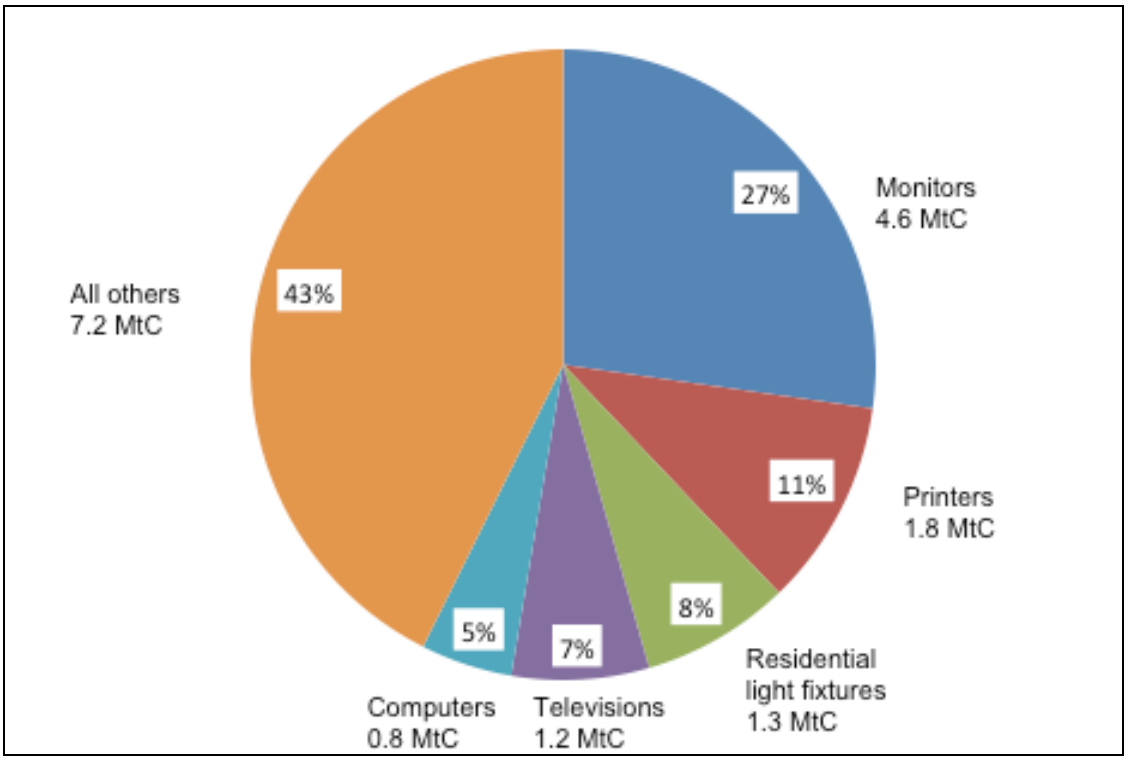
7. Results

7.1. Savings for U.S. EPA Energy Star-labeled Products

In 2007, U.S. EPA Energy Star-labeled products saved 0.97 quadrillion Btu (Quads) of primary energy and $9 billion in energy bills, and avoided 17 million metric tons carbon equivalent (MtC eq.) through its voluntary program efforts. For reference, these carbon savings represent 3% of residential and commercial building sector carbon emissions in 2007 (U.S. DOE 2008). Energy Star also saved 15 gigawatts (GW) of peak power.

The following graphic shows the share of total carbon savings achieved by the top five U.S. EPA Energy Star products in 2007 (Figure 7-1):

Figure 7-1. Carbon savings achieved in 2007



Monitors, printers, residential light fixtures, televisions, and computers accounted for nearly 60% of Energy Star product labeling savings. Projected savings for 2008 and 2009 are shown in Table 7-2 and Table 7-3**,** respectively. We project that carbon savings will increase to 20.1 MtC in 2008 and 22.4 MtC in 2009.

In contrast to the five products above, the residential and commercial appliance programs together contributed 0.5 MtC of reduction; and digital TV adapter, set-top box, battery charging systems, transformers, and residential roofing all contributed 0.0 MtC of reduction in 2007.

Table 7-1. U.S. EPA achieved annual savings in 2007

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2007	MtC		GW
Office Equipment	- Computers	47	440	0.8	1.31	0.4
	- Monitors	260	2,300	4.6	1.75	2.4
	- Faxes	3	31	0.1	1.00	0.0
	- Copiers	32	280	0.6	4.61	0.1
	-Multifunction Devices	15	140	0.3	1.00	0.2
	- Scanners	10	96	0.2	0.76	0.1
	- Printers	100	910	1.8	3.45	0.3
	Subtotal	**468**	**4,200**	**8.2**	**1.53**	**3.6**
Consumer Electronics	- TVs	70	690	1.2	1.00	0.7
	-VCRs	8	83	0.1	1.00	0.1
	-TV/VCR/DVD	15	150	0.3	1.00	0.2
	-DVD Player	14	130	0.2	1.00	0.1
	-Audio Equipment	12	120	0.2	1.00	0.1
	-Telephony	13	120	0.2	1.00	0.1
	-Digital TV Adapter	0	0	0.0	0.69	0.0
	-Set-top Box	0	0	0.0	1.00	0.0
	-External Power Supplies	26	240	0.5	1.00	0.3
	-Battery Charging Systems	0	4	0.0	1.00	0.1
	Subtotal	**159**	**1,600**	**2.8**	**1.00**	**1.7**
Heating and Cooling	- Furnace (Gas or Oil)	54	660	0.8	-	-
	- Central Air Conditioner	32	310	0.6	0.15	2.2
	- Air-Source Heat Pump	26	250	0.5	0.15	0.7
	- Geothermal Heat Pump	8	77	0.1	0.15	0.1
	- Boiler (Gas or Oil)	10	181	0.2	-	-
	- Programmable Thermostat	29	360	0.5	0.15	0.0
	- Unitary HVAC	36	320	0.6	0.15	2.5
	Subtotal	**193**	**2,200**	**3.2**	**0.18**	**5.5**
Residential and Commercial Lighting	- Fixtures	76	750	1.3	1.02	0.8
	- Exit Sign	5	44	0.1	1.00	0.1
	- Decorative Light Strands	0	0	0.0	1.02	0.0
	- Traffic Signal	10	87	0.2	1.00	0.1
	Subtotal	**91**	**880**	**1.6**	**1.01**	**0.9**
Residential Appliances	- Dehumidifiers	5	48	0.1	0.48	0.1
	- Air Cleaners	3	32	0.1	1.00	0.0
	- Exhaust Fans	1	13	0.0	1.02	0.0
	- Ceiling Fans	1	13	0.0	1.02	0.0
	Subtotal	**11**	**110**	**0.2**	**0.941**	**0.2**
Commercial Appliances	- Water Coolers	10	86	0.2	0.70	0.2
	- Commercial Refrigeration	3	31	0.1	0.95	0.0
	- Hot Food Holding Cabinets	0	0	0.0	0.95	0.0
	- Fryers	0	1	0.0	0.95	0.0
	- Steamers	0	0	0.0	0.95	0.0
	- Ice Machines	0	0	0.0	0.95	0.0
	- Dishwashers	0	0	0.0	0.95	0.0
	- Vending Machines	1	14	0.0	0.95	0.0
	Subtotal	**15**	**130**	**0.3**	**0.74**	**0.2**
Other	- Utility Transformers	0	1	0.0	1.00	0.0
	- C&I Transformers	1	9	0.0	0.77	0.0
	- Residential Roofing	1	11	0.0	0.15	0.2
	- Commercial Roofing	32	260	0.6	0.15	3.2
	Subtotal	**34**	**280**	**0.6**	**0.15**	**3.4**
TOTAL		**971**	**9,400**	**16.9**	**0.64**	**16**

Notes to Table 7-1:
1) Savings values have been rounded and columns may not sum to total due to rounding.
2) Electricity is converted to primary energy using electricity heat rates as shown in Table 4-2.
3) Energy bills are calculated using yearly U.S. average energy prices. See Table 4-2.
4) Carbon emissions for electricity are from U.S. EPA (2007b). See Table 4-2.
5) Dehumidifier CLF is based on usage patterns from Zogg and Alberino (1998). Water cooler CLF is derived from metered load data from Rovi (2001). CLFs for cooling technologies and refrigeration equipment are taken from Koomey et al. (1990). Roofs are assumed to have the same CLF as cooling technologies. Commercial cooking equipment and commercial dishwashers are assumed to have the same CLF as commercial refrigeration. CLFs for exit signs and traffic signals equal one because they operate 24 hours a day. CLFs for consumer electronics (with the exception of DTAs) equal one because savings are assumed to accrue whether the device is on or off. Office equipment CLFs are derived from assumed operating patterns (Piette et al. 1995; Nordman et al. 1998; and recent printer and scanner metered data). Ceiling fans are assumed to have the same CLF as residential lighting. Exhaust fans encompass several products. The CLF represents a weighted average of intermittent fans (assumed the same as lighting), continuously operated fans (CLF of 1), and rangehood fans (assumed the same as cooking equipment).

Table 7-2. U.S. EPA projected annual savings in 2008

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2007	MtC		GW
Office Equipment	- Computers	61	550	1.1	1.19	0.6
	- Monitors	308	2,700	5.4	1.75	2.8
	- Faxes	4	34	0.1	1.00	0.0
	- Copiers	38	330	0.7	4.61	0.1
	-Multifunction Devices	20	170	0.3	0.98	0.2
	- Scanners	11	95	0.2	0.76	0.2
	- Printers	115	1,000	2.0	3.57	0.4
	Subtotal	**554**	**4,900**	**9.8**	1.57	4.2
Consumer Electronics	- TVs	80	770	1.4	1.00	0.8
	-VCRs	6	59	0.1	1.00	0.1
	-TV/VCR/DVD	16	150	0.3	1.00	0.2
	-DVD Player	14	130	0.2	1.00	0.1
	-Audio Equipment	12	120	0.2	1.00	0.1
	-Telephony	17	160	0.3	1.00	0.2
	-Digital TV Adapter	0	0	0.0	0.69	0.0
	-Set-top Box	0	0	0.0	1.00	0.0
	-External Power Supplies	53	480	0.9	1.00	0.6
	-Battery Charging Systems	1	8	0.0	1.00	0.1
	Subtotal	**198**	**1,900**	**3.5**	**1.00**	**2.1**
Heating and Cooling	- Furnace (Gas or Oil)	56	680	0.8	-	-
	- Central Air Conditioner	34	330	0.6	0.15	2.4
	- Air-Source Heat Pump	28	270	0.5	0.15	0.7
	- Geothermal Heat Pump	11	110	0.2	0.15	0.1
	- Boiler (Gas or Oil)	11	210	0.2	-	-
	- Programmable Thermostat	31	390	0.5	0.15	0.0
	- Unitary HVAC	44	380	0.8	0.15	3.1
	Subtotal	**215**	**2,400**	**3.6**	**0.18**	**6.3**
Residential and Commercial Lighting	- Fixtures	93	890	1.6	1.02	1.0
	- Exit Sign	5	40	0.1	1.00	0.1
	- Decorative Light Strands	1	9	0.0	1.02	0.0
	- Traffic Signal	10	85	0.2	1.00	0.1
	Subtotal	**108**	**1,000**	**3.6**	**1.01**	**1.1**
Residential Appliances	- Dehumidifiers	6	61	0.1	0.50	0.1
	- Air Cleaners	5	46	0.1	1.00	0.1
	- Exhaust Fans	2	15	0.0	1.02	0.0
	- Ceiling Fans	1	14	0.0	1.02	0.0
	Subtotal	**14**	**140**	**0.2**	**094**	**0.2**
Commercial Appliances	- Water Coolers	12	100	0.2	0.70	0.2
	- Commercial Refrigeration	5	43	0.1	0.95	0.1
	- Hot Food Holding Cabinets	0	0	0.0	0.95	0.0
	- Fryers	0	1	0.0	0.95	0.0
	- Steamers	0	0	0.0	0.95	0.0
	- Ice Machines	0	1	0.0	0.95	0.0
	- Dishwashers	0	2	0.0	0.95	0.0
	- Vending Machines	3	24	0.0	0.95	0.0
	Subtotal	**20**	**180**	**0.4**	**0.75**	**0.3**
Other	- Utility Transformers	0	1	0.0	1.00	0.0
	- C&I Transformers	1	8	0.0	0.77	0.0
	- Residential Roofing	2	13	0.0	0.15	0.2
	- Commercial Roofing	35	280	0.6	0.15	3.6
	Subtotal	**37**	**310**	**0.7**	**0.15**	**3.8**
TOTAL		**1,148**	**11,000**	**20.1**	**0.66**	**18**

Notes to Table 7-2:

1) Savings values have been rounded and columns may not sum to total due to rounding.
2) Electricity is converted to primary energy using electricity heat rates as shown in Table 4-2.
3) Energy bills are calculated using yearly U.S. average energy prices. See Table 4-2.
4) Carbon emissions for electricity are from U.S. EPA (2007b). See Table 4-2.
5) Dehumidifier CLF is based on usage patterns from Zogg, R. and D. Alberino (1998). Water cooler CLF is derived from metered load data from Rovi (2001). CLFs for cooling technologies and refrigeration equipment are taken from Koomey et al. (1990). Roofs are assumed to have the same CLF as cooling technologies. Commercial cooking equipment and commercial dishwashers are assumed to have the same CLF as commercial refrigeration. CLFs for exit signs and traffic signals equal one because they operate 24 hours a day. CLFs for consumer electronics (with the exception of DTAs) equal one because savings are assumed to accrue whether the device is on or off. Office equipment CLFs are derived from assumed operating patterns (Piette et al. 1995; Nordman et al. 1998; and recent printer and scanner metered data). Ceiling fans are assumed to have the same CLF as residential lighting. Exhaust fans encompass several products. The CLF represents a weighted average of intermittent fans (assumed the same as lighting), continuously operated fans (CLF of 1), and rangehood fans (assumed the same as cooking equipment).

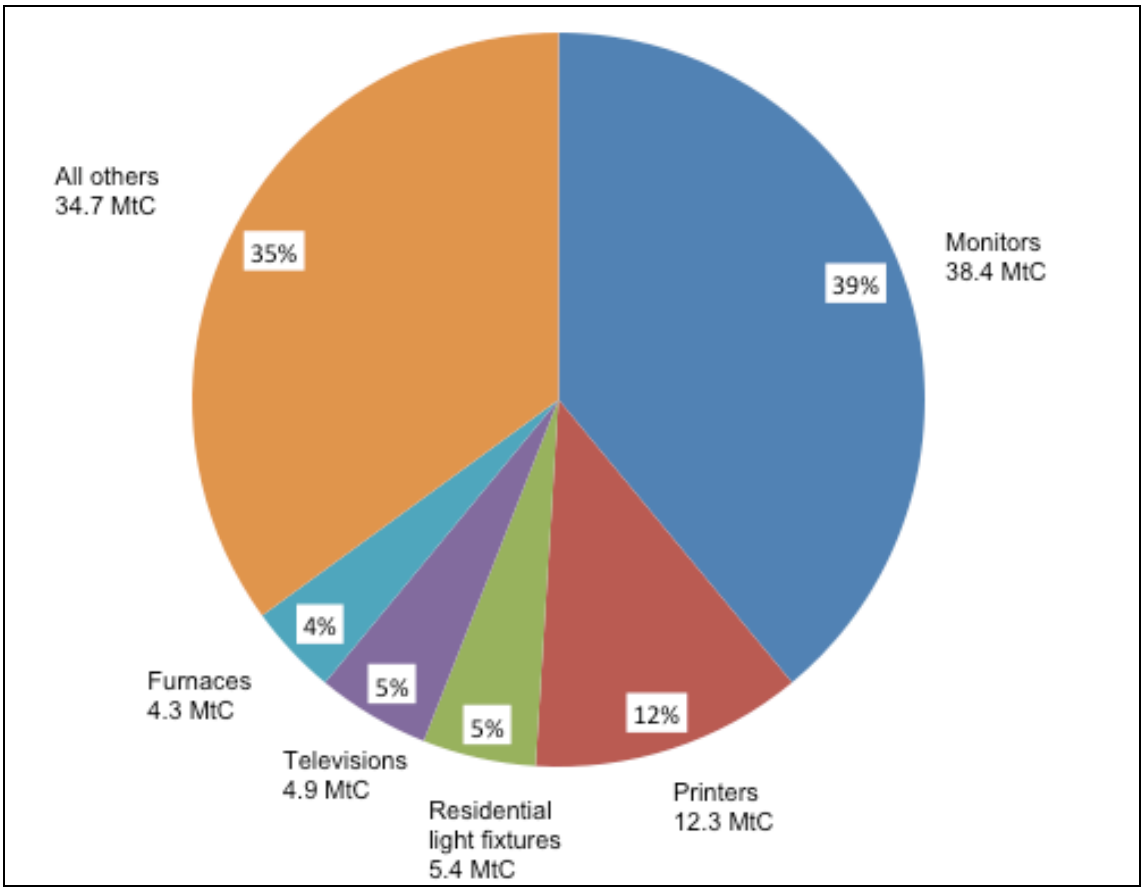
Table 7-3. U.S. EPA projected annual savings in 2009

Program	Equipment Type	Primary Savings	Energy Bill Savings, Discounted	Carbon Emissions Avoided	Conservation Load Factor	Peak Load Savings
		Trillion Btu	Million $2007	MtC		GW
Office Equipment	- Computers	80	720	1.4	1.19	0.8
	- Monitors	324	2,800	5.7	1.75	2.9
	- Faxes	4	40	0.1	1.00	0.0
	- Copiers	40	340	0.7	4.61	0.1
	-Multifunction Devices	30	260	0.5	0.97	0.3
	- Scanners	10	91	0.2	0.76	0.1
	- Printers	131	1,200	2.3	3.69	0.4
	Subtotal	**620**	**5,400**	**11.0**	**1.57**	**4.7**
Consumer Electronics	- TVs	91	870	1.6	1.00	1.0
	-VCRs	5	45	0.1	1.00	0.1
	-TV/VCR/DVD	16	150	0.3	1.00	0.2
	-DVD Player	13	130	0.2	1.00	0.1
	-Audio Equipment	13	120	0.2	1.00	0.1
	-Telephony	18	170	0.3	1.00	0.2
	-Digital TV Adapter	2	21	0.0	0.69	0.0
	-Set-top Box	4	43	0.1	1.00	0.1
	-External Power Supplies	53	480	0.9	1.00	0.6
	-Battery Charging Systems	1	12	0.0	1.00	0.0
	Subtotal	**216**	**2,000**	**3.8**	**1.00**	**2.3**
Heating and Cooling	- Furnace (Gas or Oil)	59	680	0.9	-	-
	- Central Air Conditioner	37	360	0.7	0.15	2.7
	- Air-Source Heat Pump	31	290	0.5	0.15	0.8
	- Geothermal Heat Pump	15	140	0.3	0.15	0.1
	- Boiler (Gas or Oil)	12	190	0.2	-	-
	- Programmable Thermostat	33	390	0.5	0.15	0.0
	- Unitary HVAC	53	460	0.9	0.15	3.8
	Subtotal	**240**	**2,500**	**4.0**	**0.18**	**7.3**
Residential and Commercial Lighting	- Fixtures	111	1,100	2.0	1.02	1.2
	- Exit Sign	4	35	0.1	1.00	0.0
	- Decorative Light Strands	4	34	0.1	1.02	0.0
	- Traffic Signal	10	84	0.2	1.00	0.1
	Subtotal	**128**	**1,200**	**2.3**	**1.01**	**1.3**
Residential Appliances	- Dehumidifiers	8	75	0.1	0.51	0.2
	- Air Cleaners	6	62	0.1	1.00	0.1
	- Exhaust Fans	2	18	0.0	1.02	0.0
	- Ceiling Fans	2	15	0.0	1.02	0.0
	Subtotal	**18**	**170**	**0.3**	**0.95**	**0.3**
Commercial Appliances	- Water Coolers	14	120	0.3	0.70	0.3
	- Commercial Refrigeration	7	57	0.1	0.95	0.1
	- Hot Food Holding Cabinets	0	0	0.0	0.95	0.0
	- Fryers	0	1	0.0	0.95	0.0
	- Steamers	0	0	0.0	0.95	0.0
	- Ice Machines	0	3	0.0	0.95	0.0
	- Dishwashers	1	5	0.0	0.95	0.0
	- Vending Machines	4	35	0.1	0.95	0.1
	Subtotal	**26**	**220**	**0.5**	**0.76**	**0.4**
Other	- Utility Transformers	0	1	0.0	1.00	0.0
	- C&I Transformers	1	8	0.0	0.77	0.0
	- Residential Roofing	2	17	0.0	0.15	0.3
	- Commercial Roofing	29	240	0.5	0.15	3.0
	Subtotal	**32**	**260**	**0.6**	**0.15**	**3.3**
TOTAL		**1,279**	**12,000**	**22.4**	**0.68**	**20**

Notes to Table 7-3:
1) Savings values have been rounded and columns may not sum to total due to rounding.
2) Electricity is converted to primary energy using electricity heat rates as shown in Table 4-2
3) Energy bills are calculated using yearly U.S. average energy prices. See Table 4-2.
4) Carbon emissions for electricity are from U.S. EPA (2007b). See Table 4-2.
5) Dehumidifier CLF is based on usage patterns from Zogg, R. and D. Alberino (1998). Water cooler CLF is derived from metered load data from Rovi (2001). CLFs for cooling technologies and refrigeration equipment are taken from Koomey et al. (1990). Roofs are assumed to have the same CLF as cooling technologies. Commercial cooking equipment and commercial dishwashers are assumed to have the same CLF as commercial refrigeration. CLFs for exit signs and traffic signals equal one because they operate 24 hours a day. CLFs for consumer electronics (with the exception of DTAs) equal one because savings are assumed to accrue whether the device is on or off. Office equipment CLFs are derived from assumed operating patterns (Piette et al. 1995, Nordman et al. 1998; and recent printer and scanner metered data). Ceiling fans are assumed to have the same CLF as residential lighting. Exhaust fans encompass several products. The CLF represents a weighted average of intermittent fans (assumed the same as lighting), continuously operated fans (CLF of 1), and rangehood fans (assumed the same as cooking equipment).

Through 2007, U.S. EPA Energy Star-labeled products saved 5.5 Quads of primary energy, $50 billion dollars in energy bills, and avoided 100 MtC (Table 7-4). Although Energy Star-labeled products encompass over fifty product types, only five of those product types accounted for 65% of all Energy Star carbon reductions achieved to date. Those product types are shown in Figure 7-2 (ranked by total carbon avoided through 2007).

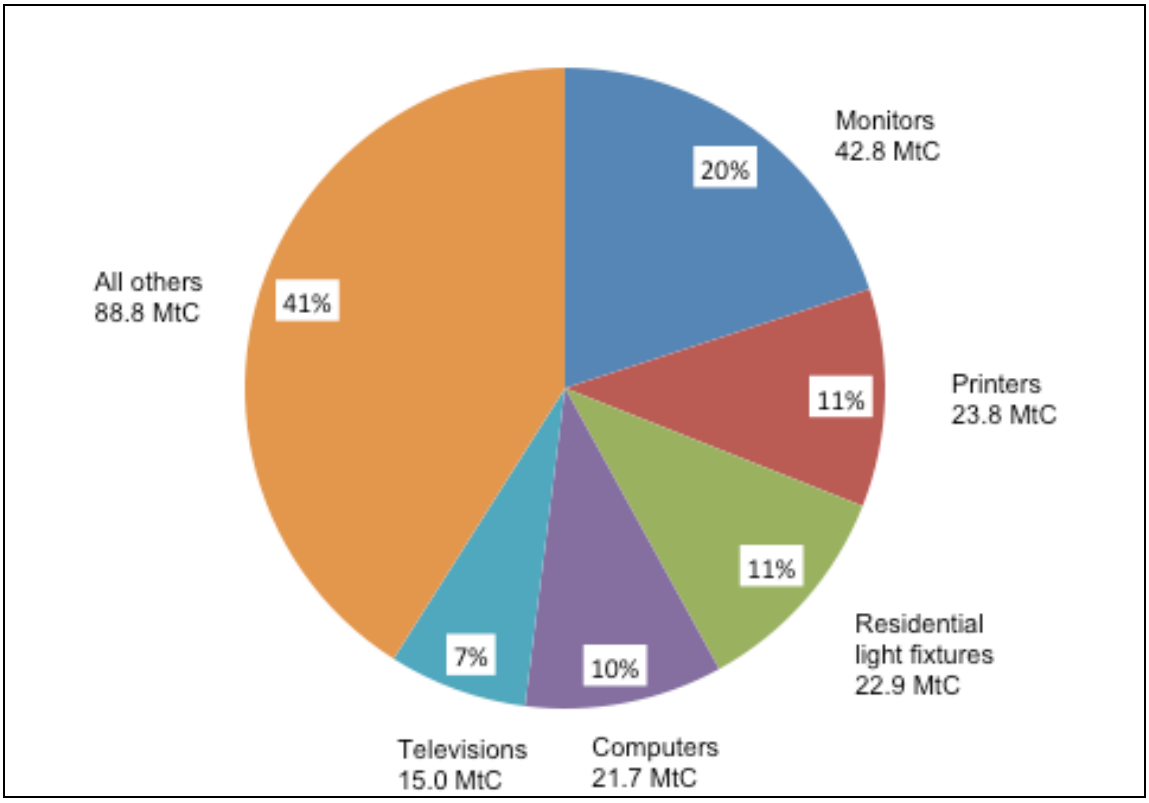
Figure 7-2. Top five carbon-reducing Energy Star product types, cumulative 1993-2007



In contrast to the five products shown above, the residential appliances, commercial appliances, transformers, and roofing Energy Star programs together (sixteen products) accounted for less than 3.5% (3.5 MtC) of carbon avoided.

Over the period 2008 to 2015,[5] U.S. EPA Energy Star-labeled products are projected to save 12 Quads of primary energy and $97 billion dollars in energy bills (4% discount rate), in addition to avoiding 220 MtC. Figure 7-3 shows the five product types that account for about 60% of future carbon avoided.

Figure 7-3. Top five future carbon-reducing Energy Star product types, cumulative 2008-2015



Again, in contrast to the five products shown above, the residential appliances, commercial appliances, transformers, and roofing Energy Star programs together (sixteen products) account for approximately 6.5% (14 MtC) of carbon avoided.

[5] We chose to present results for the period 2008–2015, even though the model results extend through 2025, to minimize the uncertainty associated with such a long forecast period.

Table 7-4. U.S. EPA cumulative savings (1993–2015)

Savings Analysis Period		Achieved Savings through 2007[1]			Projected Savings 2008–2015[1]		
Program		Primary Energy Savings[2]	Discounted Energy Bill Savings[3]	Carbon Avoided[4]	Primary Energy Savings[2]	Discounted Energy Bill Savings[3]	Carbon Avoided[4]
		Trillion Btu	Million $2007	MtC eq.	Trillion Btu	Million $2007	MtC eq.
Office Equipment	- Computers	2222	2000	4.0	1,220	9,100	21.7
	- Monitors	2,101	18,000	38.4	2,407	18,000	42.8
	- Fax	48	430	0.9	39	320	0.7
	- Copier	174	1,500	3.2	344	2,500	6.1
	-Multifunction Device	173	1,400	3.2	428	3,100	7.6
	- Scanner	76	660	1.4	76	600	1.4
	- Printer	675	5,800	12.3	1,336	10,000	23.8
	Subtotal	**3,468**	**30,000**	**63.4**	**5,850**	**44,000**	**104.1**
Consumer Electronics	- TVs	269	2,500	4.9	845	7,100	15.0
	-VCRs	93	850	1.7	14	130	0.2
	-TV/VCR/DVD	84	780	1.5	137	1,200	2.4
	-DVD Player	55	520	1.0	105	890	1.9
	-Audio Equipment	56	530	1.0	96	820	1.7
	-Telephony	33	320	0.6	145	1,200	2.6
	-Digital TV Adapters	0	0	0.0	9	78	0.2
	-Set-top Box	0	1	0.0	192	1,500	3.4
	-External Power Supplies	32	300	0.6	323	2,600	5.7
	-Battery Charging Systems	0	4	0.0	17	140	0.3
	Subtotal	**624**	**5,800**	**11.3**	**1,883**	**16,000**	**33.5**
Heating and Cooling	- Furnace (Gas or Oil)	285	3,200	4.3	530	5,200	8.0
	- Central Air Conditioner	139	1,300	2.5	357	3,000	6.4
	- Air-Source Heat Pump	102	960	1.8	291	2,400	5.2
	- Geothermal Heat Pump	16	160	0.3	194	1,600	3.4
	- Boiler (Gas or Oil)	56	780	1.0	114	1,500	2.1
	- Programmable Thermostat	188	2,100	3.0	241	2,500	3.9
	- Light Commercial HVAC	95	800	1.7	413	3,100	7.3
	Subtotal	**881**	**9,300**	**14.8**	**2,140**	**19,000**	**36.2**
Lighting	- Fixtures	298	2,800	5.4	1,285	11,000	22.9
	- Exit Sign	33	280	0.6	19	150	0.3
	- Decorative Light Strand	0	0	0.0	160	1,300	2.9
	- Traffic Signal	49	420	0.9	49	390	0.9
	Subtotal	**380**	**3,500**	**6.9**	**1,513**	**12,000**	**26.9**
Residential Appliances	- Dehumidifiers	12	110	0.2	85	700	1.5
	- Air Cleaners	6	62	0.1	90	740	1.6
	- Exhaust Fans	4	35	0.1	21	170	0.4
	- Ceiling Fans	4	42	0.1	13	110	0.2
	Subtotal	**26**	**250**	**0.46**	**208**	**1,700**	**3.7**
Commercial Appliances	- Water Coolers	28	240	0.5	152	1,100	2.7
	- Commercial Refrigeration	6	55	0.1	50	370	0.9
	- Hot Food Holding Cabinets	0	0	0.0	1	6	0.0
	- Fryers	0	2	0.0	2	12	0.0
	- Steamers	0	0	0.0	1	4	0.0
	- Ice Machines	0	0	0.0	13	89	0.2
	- Dishwashers	0	0	0.0	22	160	0.4
	- Vending Machines	3	23	0.0	70	490	1.2
	Subtotal	**37**	**320**	**0.7**	**311**	**2,200**	**5.5**
Other	- Utility Transformers	1	5	0.0	0	4	0.0
	- C&I Transformers	4	34	0.1	8	57	0.1
	- Residential Roofing	3	24	0.1	24	180	0.5
	- Commercial Roofing	114	930	2.2	224	1,600	4.2
	Subtotal	**122**	**990**	**2.3**	**256**	**1,900**	**4.8**
TOTAL		**5,538**	**50,000**	**99.7**	**12,161**	**97,000**	**214.7**

Notes to Table 7-4:
1) Savings values have been rounded and columns may not sum to total due to rounding.
2) Electricity is converted to primary energy using a conversion factor listed in Table 4-2
3) Energy bills are calculated using yearly U.S. average energy prices (Table 4-2) and they are discounted at 4%.
4) Carbon emissions for electricity are listed in Table 4-2.

Figure 7-4 below shows the primary energy savings due to the Energy Star program. The total savings through 2007 is 5.5 Quads, and the projected savings for 2008 through 2015 is 12.2 Quads.

Figure 7-4. Primary energy (in Quads) saved by program category

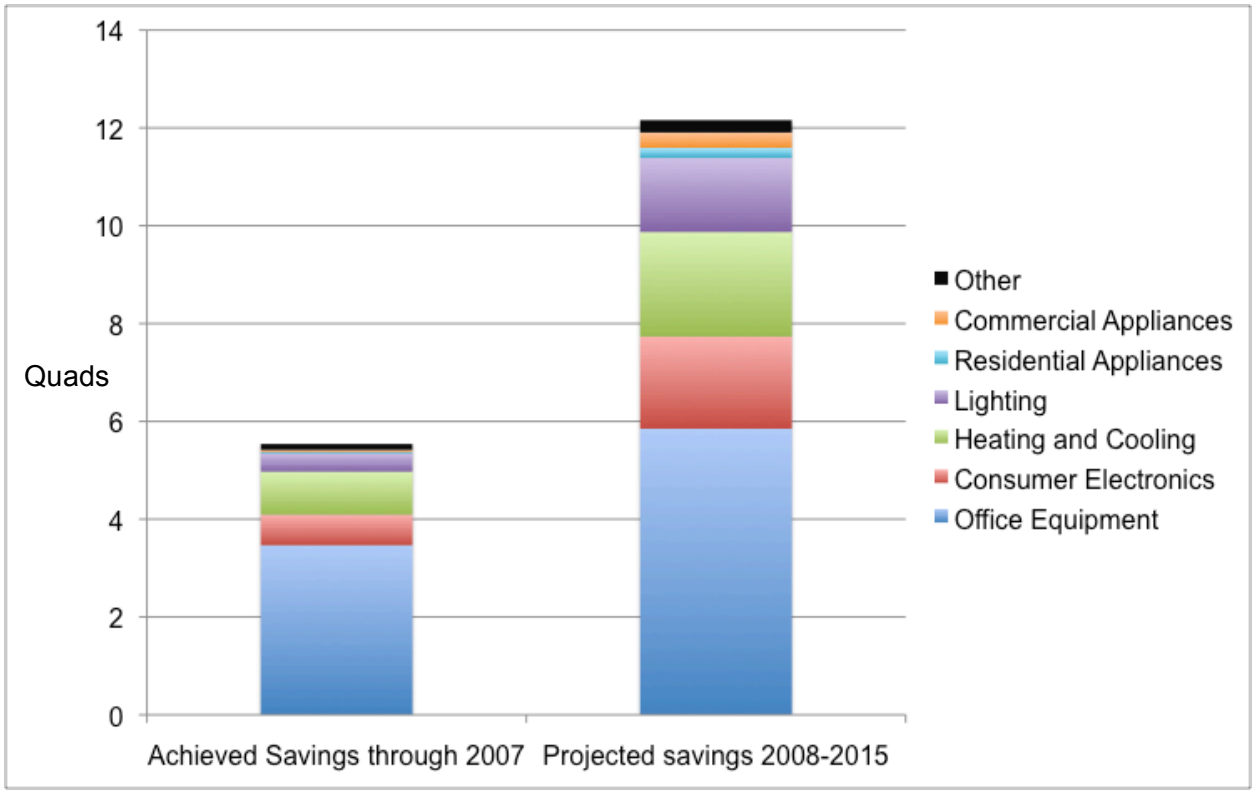
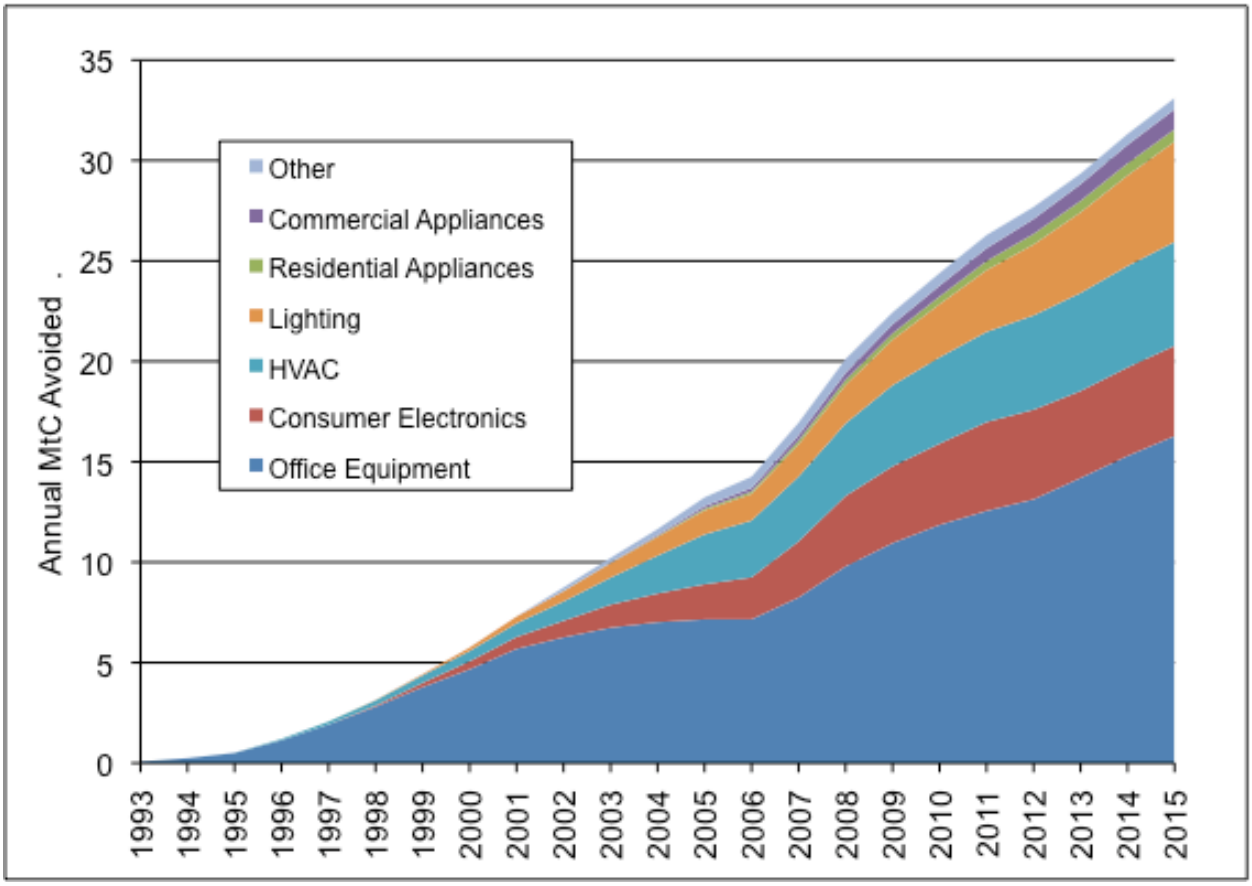


Figure 7-5 shows the allocation of carbon reductions across the seven U.S. EPA Energy Star-labeled product categories. Annual savings are estimated to increase from 0.1 MtC in 1993 to 20.1 MtC in 2008. We project that annual savings will increase to 33.1 MtC in 2015. The results show the critical importance of the office equipment and lighting product categories to overall Energy Star product savings.

In 2007, Energy Star office equipment avoided 8.2 MtC or nearly 50% of the total annual carbon reductions for Energy Star-labeled products. We expect carbon reductions for Energy Star office equipment to grow to 16.3 MtC in 2015, again representing ~50% of total annual carbon reductions. Maintaining the relevance of the Energy Star brand for office equipment will likely be a key indicator of program impact in the future.

Figure 7-5. Carbon Savings for EPA Energy Star-labeled products (1993–2015)



7.2. Sensitivity Analysis

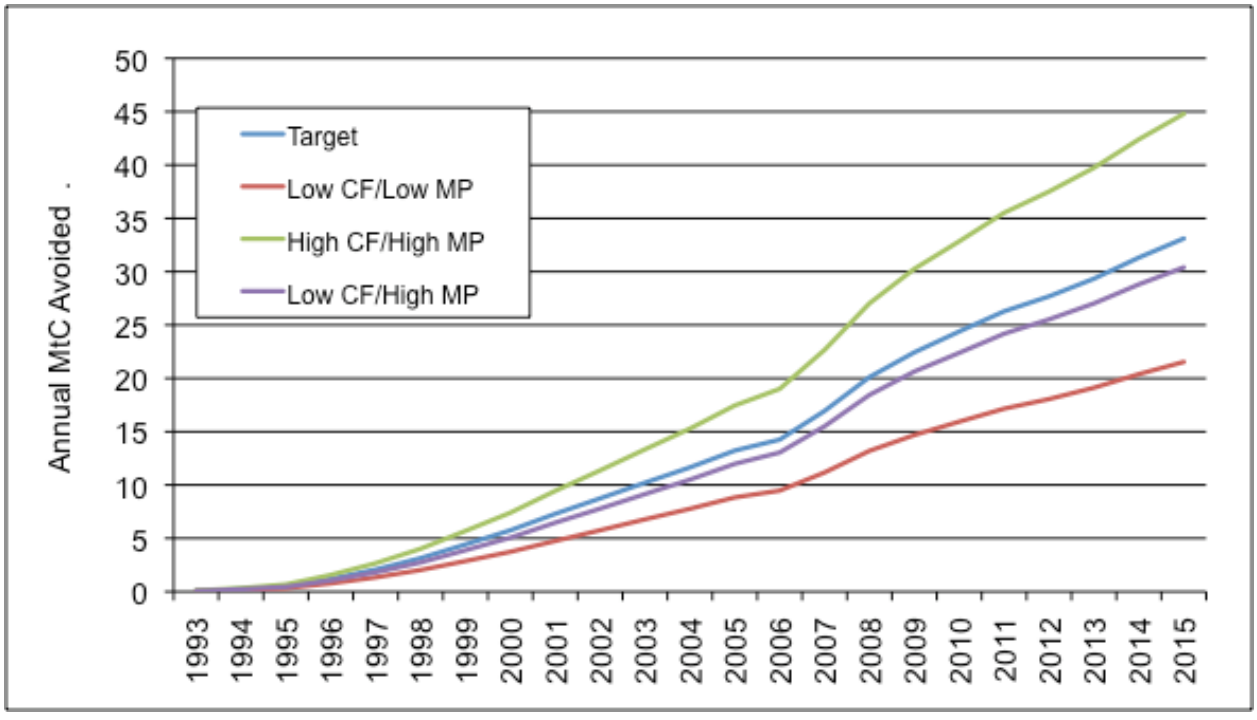
One method of addressing the uncertainty inherent in the model is to bracket the projected "best estimate" savings by varying key inputs that globally affect the model results. The most critical input to quantifying savings is the annual Energy Star unit sales, which underlies our per-product savings calculations. The Energy Star unit sales are affected by uncertainty in terms of possible reporting errors, as well as higher or lower than expected sales over our forecast period. Office equipment usage patterns are also critical to quantifying savings impact. Office equipment accounts for over half of all savings achieved to date, and prior to 2006, Energy Star only realized savings for successfully power managing units. Given the uncertainty surrounding the user operation of devices, we determined that sensitivity related to power management success rates was critical to documenting our savings estimates. In addition to these two key areas, we also evaluate the model sensitivity as it relates to higher or lower than expected carbon factors and varying energy price scenarios.

For the purposes of this report, we examined the sensitivity of the best-estimate carbon reductions by creating three general scenarios that cover the periods 1993–2007 and 2008–2015. These three scenarios are based around model sensitivity to Energy Star sales and the best estimate carbon factor. We present the following scenarios:

- The marginal carbon factor for electricity was reduced by 20% and Energy Star sales were reduced by 20%. We denote this scenario in our figure as *low CF (carbon factor)/low MP* (Energy Star market penetration). This scenario is used to estimate a lower bound savings impact.
- The marginal carbon factor for electricity was increased by 20% and Energy Star sales were increased by 20%. We denote this scenario in our figure as *high CF (carbon factor)/high MP* (Energy Star market penetration). This scenario is used to estimate an upper bound savings impact.
- The marginal carbon factor for electricity was reduced by 20% and Energy Star sales were increased by 20%. We denote this scenario in our figure as *low CF (carbon factor)/high MP* (Energy Star market penetration). This scenario is used to understand the model impact of sensitivity related to carbon factor versus Energy Star sales.

Figure 7-6 illustrates the results of this sensitivity analysis. These results bound the best estimate of carbon avoided between 66 MtC and 131 MtC for the period 1993–2007 and between 140 MtC and 290 MtC for the period 2008–2015. The fluctuation in Energy Star unit sales, fuel supply, fuel demand, and fuel mix are highly difficult to predict and model over the 23-year analysis period. However, even in a "worst case" scenario, the analysis shows substantial reductions in carbon achieved by Energy Star-labeled products. The results of this sensitivity analysis are used to inform data collection priorities, target retail outreach and sales efforts, and internally assess and verify program goals/accomplishments.

Figure 7-6. Sensitivity analysis of carbon savings (1993–2015)



7.3. Market Transformation Analysis

Table 7-5 shows the quantitative impact of the market transformation effect on savings. From 1993–2007, U.S. EPA Energy Star products realized 5.6 MtC due to the market transformation methodology. This represents about 5.5% of total U.S. EPA savings during that period. CRT monitors, televisions, audio equipment, and telephony had the highest market transformation impact.

Future market transformation impacts are larger. We project that from 2008–2015, U.S. EPA will realize 18 MtC from the market transformation methodology (roughly 8% of projected savings). The higher projected savings are due to two factors: (1) there are a significant number of specification changes circa 2007–2009, which accrue market transformation savings into the forecast period; and (2) we are conservative in estimating Energy Star sales in years following specification changes. This results in a larger amount of sales being attributed to "former" Energy Star units. We typically find that actual Energy Star sales for office and electronics products are higher than we anticipated following specification changes. If this trend continues, the market transformation effect will be lowered when actual sales data are collected in future years (2008 and 2009 in particular due to the computer and television specification revision).

Table 7-5. Quantitative impact of market transformation effect (MTE)

Program	Equipment Type	Years MTE Yields Sales	Carbon Emissions Avoided (1993-2007) MtC	Carbon Emissions Avoided (2008-2015) MtC
Office Equipment	- Computer	1999; 2008–2025	0.0	3.2
	- Monitor	1999; 2002–2025	2.3	0.8
	- Fax	2007–2025	0.0	0.0
	- Copier	2000–2002; 2007–2025	0.1	0.4
	-Multifunction Device	2007–2010	0.0	0.1
	- Scanners	2007–2008; 2012–2025	0.0	0.0
	- Printer	2001–2003; 2007–2025	0.4	0.9
	Subtotal		**2.8**	**5.6**
Consumer Electronics	- TV	2005–2025	0.4	3.2
	-VCR	2005	0.0	0.0
	-TV/VCR/DVD	2005–2025	0.4	2.9
	-DVD Player	2004–2006	0.2	0.3
	-Audio Equipment	2003–2025	1.0	1.7
	-Telephony	2006–2025	0.6	2.6
	-Digital TV Adapter	none	NA	NA
	-Set-top Box	none	NA	NA
	-External Power Supply	2009–2025	0.0	0.1
	-Battery Charging System	none	NA	NA
	Subtotal		**2.6**	**10.8**
Heating and Cooling	- Furnace (Gas or Oil)	none	NA	NA
	- Central Air Conditioner	2002–2021	0.1	0.9
	- Air-Source Heat Pump	2003–2025	0.1	0.8
	- Geothermal Heat Pump	none	NA	NA
	- Boiler (Gas or Oil)	none	NA	NA
	- Programmable Thermostat	none	NA	NA
	- Unitary HVAC	none	NA	NA
	Subtotal		**0.2**	**1.7**

Note: The methodology is described in Section 4.3. Table 4-3 summarizes the calculation approach for quantifying market transformation impacts.

Table 7-5, continued.

Program	Equipment Type	Years MTE Yields Sales	Carbon Emissions Avoided (1993-2007) MtC	Carbon Emissions Avoided (2008-2015) MtC
Residential and Commercial Lighting	- Fixture	none	NA	NA
	- Exit Sign	none	NA	NA
	- Decorative Light Strand	none	NA	NA
	- Traffic Signal	none	NA	NA
	Subtotal		**NA**	**NA**
Residential Appliances	- Dehumidifier	2007–2025	0.0	0.0
	- Air Cleaner	none	NA	NA
	- Exhaust Fan	none	NA	NA
	- Ceiling Fan	none	NA	NA
	Subtotal		**0.0**	**0.0**
Commercial Appliances	- Water Coolers	none	NA	NA
	- Commercial Refrigeration	none	NA	NA
	- Hot Food Holding Cabinets	none	NA	NA
	- Fryers	none	NA	NA
	- Steamers	none	NA	NA
	- Ice Machines	none	NA	NA
	- Dishwashers	none	NA	NA
	- Vending Machines	none	NA	NA
	Subtotal		**NA**	**NA**
Other	- Utility Transformers	none	NA	NA
	- C&I Transformers	none	NA	NA
	- Residential Roofing	none	NA	NA
	- Commercial Roofing	none	NA	NA
	Subtotal		**NA**	**NA**
TOTAL			**5.6**	**18.0**

Note: The methodology is described in Section 4.3. Table 4-3 summarizes the calculation approach for quantifying market transformation impacts. “NA” signifies that the market transformation effect is not applicable.

8. Limitations to the Analysis

8.1. General Limitations

The analysis is based on a bottom-up model for quantifying U.S. EPA Energy Star-labeled product savings. General limitations to a bottom-up approach occur in two main areas: (1) the model requires numerous detailed inputs to generate the end result, and (2) uncertainty in those inputs are additive through the process. These limitations mean that collecting and documenting high-quality inputs, which can be a labor-intensive and expensive process, is essential. As a result, identifying areas of critical uncertainty and sensitivity and then targeting data collection and verification activities at those areas is key to successful results. We categorize the analysis limitations in three main areas: forecasting, inputs, and model structure, as shown in Table 8-1.

Table 8-1. Limitations to analysis

Forecasting	Inputs	Model Structure
1. Projecting future Energy Star unit sales 2. Projecting key global inputs (energy prices, electricity heat rates, carbon emission factors) 3. Projecting changes in business-as-usual efficiency 4. Identifying and incorporating emerging or new technologies	1. UECs based on underlying power and usage patterns that can vary within a product type or at the consumer, organization, or regional level 2. UECs represent a national average 3. Power and usage data are often based on a smaller and regionally based sample (particularly in the case of office equipment and consumer electronics) 4. Power and usage change over time and need to be tracked consistently	1. Only includes finalized Energy Star specifications and national energy efficiency standards 2. Attributes all savings to U.S. EPA and does not reconcile Energy Star savings with supporting utility and procurement programs 3. Does not rigorously capture new/emerging technologies and their effects on baseline efficiency and Energy Star savings 4. Model is reactive rather than anticipatory, meaning that the model is updated subsequent to a technology market changing

8.2. Specific Limitations

Key limitations include those discussed in the following paragraphs.

Power consumption and energy consumption data are primarily from manufacturer test data that are submitted at the time of specification development or specification revision. In the case of office equipment and consumer electronics, the manufacturer test data are often supplemented with independent field measurements collected by LBNL and other researchers. However, in many cases such as commercial kitchens, small appliances, and power supplies, the industry data

are not supplemented, which means they are taken at face value and assumed to be representative of the entire market. These test data are also used to set the reference case market penetrations.

The model is built upon Energy Star unit sales data, which are reported by manufacturing partners. Reporting accuracy, as well as response rate, can significantly affect the results. These two factors are beyond LBNL's control, although inspection and verification of the input data help avoid significant problems.

The savings in this report represent a program savings scenario, which is constructed on a REF forecast of what would have happened in the absence of the Energy Star program. In cases such as office equipment and consumer electronics, the program savings scenario can significantly differ from actual market impacts in a given year or consumer savings from purchasing a non-Energy Star model versus an Energy Star model.

It is difficult to predict what would have happened in the absence of Energy Star over the past 15 years. One important assumption is that in the absence of Energy Star power management would not exist in our baseline. While true at the start of Energy Star, it is difficult to verify this assumption over time, since many electronic devices today are equipped with power management capabilities.

The market transformation effect is an important concept, as it quantifies Energy Star's lasting effect in the market. The current model structure, however, makes it difficult and labor intensive to collect the necessary data to carefully document and evaluate Energy Star's effect during specification changes related to models that no longer can qualify for the program.

8.3. Future Work to Address Limitations

We are planning the following activities to address these limitations:

- Review office equipment baseline assumptions for reasonableness.

- Our HVAC analysis is currently based on the Residential Energy Consumption Survey (RECS) (U.S. DOE 1995). The HVAC baseline represents a federal minimum efficiency standard, which may not represent REF conditions (in particular for gas furnaces). Our plan is to update our HVAC analysis to RECS 2005 and reevaluate REF efficiencies for certain products.

- Our thermostat savings are currently based on a consultant report (RLW Analytics 2007) that is specific to gas heating savings. We apply the gas heating percent savings to electric heating as well. The reality is that there are very limited in-field documentation studies of thermostat savings. Although we try to be conservative (for example, we do not include cooling savings), the thermostat savings are highly uncertain. We plan to evaluate whether we should be taking credit for any electric heating savings to further limit savings claims.

- We plan to evaluate the methodology used for the market transformation effect, to assess whether the savings claims made from this effect are justifiable.

- Creating a separate model to track Energy Star market and consumer savings (i.e., estimating the savings a consumer would realize today by purchasing an Energy Star-qualified unit versus a non-qualified unit) in addition to program savings.

9. Conclusions

Since the program's inception in 1992, Energy Star has become a leading international brand for energy-efficient products. As such, Energy Star achievements to date and projected savings have a critical impact on the success of both U.S. and international energy-efficiency programs. This report summarizes energy, carbon, and monetary impacts from U.S. EPA's Energy Star voluntary product labeling program. Regional, national, and international stakeholders can use these results to evaluate energy efficiency opportunities associated with the Energy Star program.

U.S. EPA's Energy Star-labeled products have been successful in reducing carbon emissions through its voluntary labeling efforts. Through 2007, U.S. EPA Energy Star-labeled products saved 5.5 Quads of primary energy and avoided 100 MtC. The forecast shows that this U.S. EPA program is expected to save 12.2 Quads of primary energy and avoid 215 MtC over the period 2008–2015. The sensitivity analysis bounds the best estimate of carbon avoided between 66 MtC and 131 MtC (1993 to 2007) and between 140 MtC and 290 MtC (2008 to 2015).

Much of the U.S. EPA's success to date is attributable to Energy Star office equipment and lighting. The analysis demonstrates the continued importance of these product categories toward realizing future Energy Star program goals. Strategies for continued success include maintaining program relevance through tightened specifications, exploring new approaches to improving a product's energy performance (including new technologies and market trends), and broadening the portfolio of office equipment products covered by the Energy Star program.

10. References

Abraham, M. 2008. *Worldwide Market for IP Set-top Boxes.* Scottsdale, Arizona: In-Stat.

AHAM (Association of Home Appliance Manufacturers). 2000. Dehumidifier Unit Sales by Capacity. Prepared for U.S. EPA Energy Star.

AHAM. 2003. Energy Consumption Test Data of Room Air Cleaners. Prepared for U.S. EPA Energy Star.

Altamura, S. 2006. Energy Star Decorative Light Strands Reference Case Market Penetration. In B. Atkinson (Ed.). Eden Prairie, Minnesota: Seasonal Specialties, Inc.

Appliance Magazine. 2000. 47th Annual Report: A Ten Year Review 1988–1999 of the U.S. Appliance Industry. *Appliance Magazine,* May, 63–66.

Appliance Magazine. 2003. 50th Annual Report: A Ten Year Review 1993–2002 of the U.S. Appliance Industry. *Appliance Magazine,* May.

Appliance Magazine. 2006. 53rd Annual Report: A Ten Year Review 1996–2005 of the U.S. Appliance Industry. *Appliance Magazine,* May.

Appliance Magazine. 2007a. 54th Annual Report: A Ten Year Review 1997–2006 of the U.S. Appliance Industry. *Appliance Magazine,* May.

Appliance Magazine. 2007b. 55th Annual Appliance Industry Forecast. *Appliance Magazine,* January.

ARI (Air conditioning Refrigeration Institute). 2001. U.S. Energy Star shipment data for Central Air Conditioners and Air Source Heat Pumps. Unpublished Spreadsheet prepared for U.S. EPA by ARI. Air Conditioning and Refrigeration Institute: Prepared for U.S. EPA Energy Star.

Beavers, D. 2007. Energy Star Projected Shipments of Set-top Boxes Version 2.0 Specification. (spreadsheet). Waltham, Massachusetts: The Cadmus Group, Inc.

Brown, R., C. Webber, J. Koomey. 2002. "Status and Future Directions of the Energy Star Program." *Energy—The International Journal* 27(5). Also published as LBNL-50859; Lawrence Berkeley National Laboratory, Berkeley California. May. 505–520.

Cadmus Group. (Cadmus Group) and Energy Systems Consulting, Inc. 1998. *Regional Electricity Emissions Factors: Final Report.* Prepared for the U.S. Environmental Protection Agency, Atmospheric Pollution Prevention Division under contract 68-W6-0050. Washington, D.C. November.

Cadmus Group. 1999a. *Preliminary market background report for bottled water coolers.* Prepared for the U.S. Environmental Protection Agency, Climate Protection Division under contract 68-W6-0050. Washington, D.C. September.

Cadmus Group. 1999b. *Preliminary market background report for ice makers* Prepared for the U.S. Environmental Protection Agency, Climate Protection Division under contract 68-W6-0050. Washington, D.C. July.

Cadmus Group. 1999c. *Preliminary Market Background Report for Residential Dehumidifiers.* Prepared for the U.S. Environmental Protection Agency. September.

Cadmus Group. 1999d *Preliminary Market Background Report for Residential Ventilation Fans.* Prepared for the U.S. Environmental Protection Agency. June.

Cadmus Group. 2000a. *Product testing and analysis of water dispensers.* Prepared for the U.S. Environmental Protection Agency, Climate Protection Division, Energy Star program under contract 68-W6-0050. Washington, D.C. February.

Calwell, C., and C. Granda. 1999. *Halogen Torchiere Market Transformation: A Look at Progress to Date and Future Strategies.* Durango, Colorado. Ecos Consulting: Prepared for the Natural Resources Defense Council.

Calwell, C., C. Granda, L. Gordon, and M. Ton. 1999a. *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets (Volume 2).* San Francisco, California. Ecos Consulting: Prepared for the Natural Resources Defense Council.

Calwell, C., C. Granda, L. Gordon, and M. Ton. 1999b. *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets (Volume 1).* San Francisco, California. Ecos Consulting: Prepared for the Natural Resources Defense Council.

Calwell, C. 2000. Field Power Measurements of Personal Computers. Durango, Colorado. Ecos Consulting.

Calwell, C., and N. Horowitz. 2001. "Ceiling fans: Fulfilling the energy efficiency promise." *Home Energy Magazine* January/February: 24–29.

Calwell, C., and T. Reed. 2001. Power Supply Numbers and Energy Use Totals. In C. Webber (Ed.) (Excel workbook, ed.). Durango, Colorado: Ecos Consulting.

Calwell, C. 2003. *The European Code of Conduct: How can you lead a global effort to improve power supply efficiency*? Presented to the European Commission-Directorate General JRC, Joint Research Center, Institute for Environment and Sustainability, Renewable Energies Unit. Ispra, Italy. April.

CEA. 2000. Personal communication: email from Joe Peck, CEA Director of Congressional Affairs to Craig Hershberg of U.S. EPA. September.

CEA. 2001. Personal communication: Email from Brian Gura (Industry Analyst, Market Research Department, CEA) to Marla McWhinney of U.S. EPA. June.

CEA. 2001a. *Domestic Sales of Telephony Products (530-M)*. Arlington, Virginia.

CEA. 2001b. *Domestic Sales of Telephony Products (531-M)*. Arlington Virginia.

CEA. 2002. *Domestic Sales of Telephony Products (531-M)*. Arlington Virginia.

CEA. 2003. Personal communication: Letter and spreadsheet (EIA_TV VCR Report 3-03.xls) from Doug Johnson (CEA) and Jason Linnell (EIA) to Ann Bailey of U.S. EPA. April.

CEA. 2004. U.S. Consumer Electronics Sales & Forecasts 1999–2004. January.

CEA.2005. Personal communication: spreadsheet (EnergyStar Report 2005.xls) from Kurt Roth (Tiax) to Marla Sanchez (LBNL).

CEA. 2006. U.S. Consumer Electronics Forecast 2002–2007. July.

CEA. 2007a. *Domestic Sales of Telephony Products (530-M)*. Arlington Virginia.

CEA. 2007b. *Domestic Sales of Telephony Products (531-M)*. Arlington Virginia.

CEC (California Energy Commission). 2001. Appliance database. www.energy.ca.gov/efficiency/appliances/index.html.

CNET. 2005. Power consumption results for twenty televisions tested.

CNET 2007. 54 TVs Power Consumtion Compared. *CNET Reviews* Retrieved September, 2007.

Darnell Group, Inc. 2008. External AC-DC Power Supplies, Worldwide Forecasts. Third edition. May.

Dataqest. 1994. Energy Efficient Personal Computer Market Trends. Prepared for the U.S. EPA. Energy Star Program. Washington D.C. November.

Dataqest. 1996. Energy Star Compliant PCs, Copiers and Printers. Prepared for U.S. EPA. Energy Star Program. Washington D.C. August.

DisplaySearch. 2007. *North American Sales of Televisions 2006–2011*.

Duff, Becky. ICF Consulting. 2005. Personal communication, email regarding market for steamers.

Duff, Becky. ICF Consulting. 2006. Personal communication, email regarding energy consumption of refurbished vending machines. August 23.

Durgin, G. 1999. *Super High-flux: The State of the Art for LED Traffic Signals.* Paper presented at the Traffic Technology International. Dorking, United Kingdom.

EIRI (Economic Industry Reports, Inc.) 1995. *The U.S. Lighting Fixtures Industry: An Economic and Market Study, 1995–96 Edition, Volumes I and II.* Raleigh, North Carolina.

ESource. 1994. *Lighting Technology Atlas.* Boulder, Colorado.

Floyd, D., and C. Webber. 1998. "Leaking electricity: Individual field measurements of consumer electronics." In *Proceedings of the 1998 Summer Study on Energy Efficiency in Buildings.* Washington D.C.: American Council for an Energy Efficient Economy. August.

Freedonia. 1997. *Roofing to 2001*. Cleveland, Ohio: The Freedonia Group, Inc.

Gartner Research. 2001. *Special report prepared for the United States Environmental Protection Agency: Energy Star Market Share of computers, monitors, printers, copiers, facsimile, and MFDs.* Washington, D.C.

Guo, J. L., L. H. Lapera, A. Manning, P. Nappakaokeskui, and M. Wyche. 1998. *Fall 1998 Report Forecasts: The Computer Hardware Industry.* Syracuse University Press.

Hanford, J., J. Koomey, L. Stewart, M. Lecar, R. Brown, F. Johnson, et al. 1994. *Baseline Data for the Residential Sector and Development of a Residential Forecasting Database.* Berkeley, California: Lawrence Berkeley National Laboratory.

Horowitz, Marvin. 2001. "Economic indicators of market transformation: Energy efficient lighting and EPA's Green Lights." *The Energy Journal* 22(4): 95–122.

Horowitz, Marvin. 2004. "Electricity intensity in the commercial Sector: Market and public program effects." *The Energy Journal* 25(2): 115–137.

Horowitz, Marvin J. 2007. "Changes in electricity demand in the United States from the 1970s to 2003." *The Energy Journal* 28(3).

Horowitz, N. 2004. NAMA Energy Consumption Test Data of Refrigerated Beverage Vending Machines. San Francisco, California: Natural Resources Defense Council. Prepared for U.S. EPA Energy Star. 1.

ICF Consulting. 2002. *Vending Market and Industry Final Draft.* Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. July.

ICF Consulting. 2003. *Energy Star Market Penetration Report Calendar Year 2002*. Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. June.

ICF Consulting. 2004. *Energy Star Market Penetration Report Calendar Year 2003*. Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. September.

ICF Consulting. 2005a. *Ice Machine Characterization, Final Draft*. Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. July.

ICF Consulting. 2005b. *Market Research on Excluded Battery Charging Systems in Home Appliance and Power Tools.*

ICF Consulting. 2006a. *Energy Star Unit Shipment Data Report Calendar Year 2004.* Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. January.

ICF Consulting. 2006b. *Energy Star Unit Shipment Data Report Calendar Year 2005 (Final Draft)*. Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. August.

ICF Consulting. 2007. *Energy Star Unit Shipment Data Report Calendar Year 2006 (Final Draft)*. Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. May.

ICF Consulting. 2008. *Energy Star Unit Shipment Data Report Calendar Year 2007 (Final).* Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Energy Star Program. Washington, D.C. July.

IDC. 2001. Worldwide PC Monitor Forecast and Analysis 2000–2005. Farmingham Massachussets. 1–83.

IDC. 2003. Worldwide PC Monitor Forecast and Analysis 2003–2007. Farmingham, Massachussets. Report number 30629. 1–94.

IDC. 2006a. Worldwide Copier Forecast and Analysis 2006–2010. IDC number 204911.

IDC. 2006b. Worldwide MFP Forecast and Analysis 2006–2010. IDC number 204136.

IDC. 2006c. Worldwide Printer 2006–2010 Forecast and Analysis. Report number 203992.

IDC. 2006d. Worldwide PC 2006–2010 Forecast and Analysis.

IDC. 2007. Worldwide PC Monitor Forecast and Analysis 2007–2011: It's a Flat Out Success.

Farmingham, Massachussets. 1–89.

KEMA Inc. 2005. *CFL metering study final report*. Prepared for Pacific Gas and Electric (San Francisco, California), San Diego Gas and Electric (San Diego, California), and Southern California Edison (Rosemead, California). Oakland, California. February.

Konopacki, S., H. Akbari, M. Pomerantz, S. Gabersek, and L. Gartland. 1997. *Cooling energy savings potential of light-colored roofs for residential and commercial buildings in 11 US metropolitan Areas*. LBNL-39433. Berkeley, California: Lawrence Berkeley National Laboratory. May.

Koomey, Jonathan, Arthur H. Rosenfeld, and Ashok K. Gadgil. 1990. "Conservation Screening Curves to Compare Efficiency Investments to Power Plants." *Energy Policy* 18(8) October: 774–782.

Lee, J. 1999. Energy Star Office Equipment Program. Lawrence Berkeley National Laboratory. Excel workbook. October.

Lee, J., R. Brown, and B. Nordman. 2000. Power Consumption of Commercial Printers, Draft, Lawrence Berkeley National Laboratory. Spreadsheet. February.

Lyra. 1999. US Lyra Shipments Summary. The Lyra Hardcopy Industry Advisory Service. Excel spreadsheet. April.

McWhinney, M., A. Fanara, R. Clark, C. Hershberg, R. Schmeltz, and J. Roberson. 2005. "Energy Star product specification development framework: Using data and analysis to make program decisions." *Energy Policy* 33: 1613–1625.

Media Metrix. 2001. *Hard Scan Volume 1 and Softscan (Third Quarter)*. Released as electronic data. New, York, New York.

NAFEM (North American Association of Food Equipment Manufacturers). 2002. Size and Shape of the Industry Study: Refrigeration and Ice Machines.

NAFEM. 2004a. Size and Shape of the Industry Study: Storage and Handling Equipment.

NAFEM. 2004b. Size and Shape of the Industry Study: Primary Cooking Equipment.

NAFEM. 2004c. Size and Shape of the Industry Study: Warewashing Equipment.

Navigant Consultanting. 2006. *Decorative Light String Market Assessment Report.* San Francisco, California. On Behalf of Natural Resources Defence Council: Prepared for Natural Resources Canada.

Nordman, B., M. A. Piette, B. Pon, and K. Kinney. 1998. *It's midnight...is your copier on: Energy Star copier performance*. LBNL-41332. Berkeley, California: Lawrence Berkeley National Laboratory. February.

Nordman, B., and J. McMahon. 2004. *Developing and testing low power mode measurement methods*. Prepared for the California Energy Commission, Public Interest Research Program (PIER), by Lawrence Berkeley National Laboratory under contract 500-99-013-TA20-5. CEC paper 500-04-057. Berkeley, California. September.

NRCA (National Roofing contractors Association). 2003. 2002–2003 U.S. Roofing Survey. Prepared for U.S. EPA Energy Star.

NYSERDA (New York State Energy Research and Development Authority). 2006. *Workbook Documenting Calculations*. Appliance Standards and Advisory Committee: Consumer Audio and Video Products – DTAs. June.

Oak Ridge National Laboratory (ORNL). 1996. *Determination analysis of energy conservation standards for distribution transformers*. ORNL-6847. Oak Ridge, Tennessee.

Patel, R. 2005. LCD TV Shipments Soar - Will They Bring Early Demise of CRTs? El Segundo, California: iSuppli. 1–35.

Peck, J. 2000. Energy Star Electronics Market Shares 1998 and 1999. In C. Hershberg (Ed.). Washington D.C.: Consumer Electronics Association.

Piette, M.A., M. Cramer, J. Eto, and J. Koomey. 1995. *Office technology energy use and savings potential in New York*. Completed for the New York State Energy Research and Development Authority and Consolidated Edison by Lawrence Berkeley Laboratory. Contract #1955-EEED-BES-93. Also published as LBL-36752, Berkeley, California. January.

Porter, S., L. Moorefield, and P. May-Ostendorp. 2006. *Final field research report*. Prepared for the California Energy Commission Public Interest Research Program (PIER) by Ecos Consulting under contract 500-04-030. Durango, Colorado. October.

Paxton, M. 2007. *The Cable Set-top Box Market: Demand in China Drives Growth*. Scottsdale, Arizona: In-Stat.

RLW Analytics. 2007. *Validating the impact of programmable thermostats: Final report*. Prepared for GasNetworks by RLW Analytics. Middletown, Connecticut. January.

Roberson, J. 2000. Scanner energy analysis. (Spreadsheet: Scanner Metering Results 00.xls). Lawerence Berkeley National Laboratory.

Roberson, J. 2001. Ventilation fan energy analysis. (Spreadsheet Ventfans1.xls). Berkeley, California: Lawerence Berkeley National Laboratory (based on Home Ventilating Institute Directory of Certified Products and Product literature from Broan, Nutone, Panasonic, Tamarack, Venmar, and Aldes). Lawerence Berkeley National Laboratory.

Roberson, J. A., C. Webber, M. McWhinney, R. Brown, M. Pinckard, and J. Busch. 2004. *After-hours power status of office equipment and energy use of miscellaneous plug-load equipment*. LBNL-53729. Revised. Berkeley, California. Lawrence Berkeley National Laboratory. May.

Roberson, Judy. 2002. Results of Metering Laptop Battery Charging. Prepared for U.S. EPA Energy Star Program. Memo to Andrew Fanara (EPA). September.

Roberson, J., G. Homan, et al. 2002. Energy Use and Power Management in New Personal Computers and Monitors. 2002 Summer Study on Energy Efficiency in Buildings, Asilomar Conference Center, Pacific Grove, California, American Council for an Energy Efficient Economy.

Robinson, Lee. 2005. *An Overview of the Ceiling Fan Market.* Unpublished paper submitted to U. S. EPA.

Rosen, K., and A. Meier. 1999b. *Energy Use of Televisions and Videocassette Recorders in the U.S.* Berkeley, California: Lawrence Berkeley National Laboratory.

Rosen, Karen, Alan Meier, and Stephan Zandelin. 2001. *Energy Use of Settop Boxes and Telephony Products in the US.* LBNL-45305. Lawrence Berkeley National Laboratory. June.

Roth, K., and K. McKenney. 2007. *Residential consumer electronics electricity consumption in the United States.* Published in the proceedings from the 2007 European Council for an Energy Efficient Economy (ECEEE) Summer Study. La Colle sur Loup, France, June 4–9.

Roth, K. W., K. McKenney, R. Ponoum, and C. Pactsch. 2007. *Miscellaneous Electric loads: Energy Consumption and Savings Potential.* July.

Rovi, J. 2001. Measured Energy Consumption Data for Water Coolers. In C. Webber (Ed.) (spreadsheet used to calculated CLF ed.). Washington D.C.: The Cadmus Group, Inc.

Sawyer, Richard. 2004. *Calculating Total Power Requirements for Data Centers.* American Power Conversion.

Suozzo, M., and S. Nadel. 1998. *Selecting targets for market transformation programs: A national analysis.* Published by the American Council for an Energy Efficient Economy, Washington, D.C. August.

Suozzo, Margaret. 1998. *A Market Transformation Opportunity Assessment for LED Traffic Signals*. Published by the American Council for an Energy Efficient Economy. Washington, D.C. April.

Thorne Amann, J. 2004. *Set-top Boxes: Opportunities and Issues in Setting Efficiency Standards*. Washington D.C.: American Council for an Energy Efficient Economy (ACEEE).

TIAX. 2006. U.S. Residential Information Technology Energy Consumption in 2005 and 2010. Prepared for the U.S. DOE Building Technologies Program. March.

TPU (Tacoma Public Utilities). 1996. Measured Loads of Residential Lighting. Unpublished Spreadsheet analysis of indoor and outdoor fixtures.

Tribwell, L., and D. Lerman. 1997. Baseline Residential Lighting Energy Use Study. Tacoma Public Utilities. (Spreadsheets: TPU_piviot.xls and TPU_pivot5.xls,). Lawrence Berkeley National Laboratory.

Updyke, C. 2003. U.S. Shipments of Exit Signs by Technology. Washington D.C.: National Electrical Manufacturers Association.

U.S. DOC. 1997. *Electric Lighting Fixtures 1996*. Washington D.C.: U.S. Department of Commerce, Bureau of the Census.

U.S. DOC. 2007a. *Electric Lighting Fixtures and Lamps 2000–2006*. Washington D.C.: U.S. Department of Commerce, Bureau of the Census, Prepared by the Office of Trade and Industry Information.

U.S. DOC. 2007b. Bureau of Economic Analysis, National Economic Accounts. *Current dollar and real gross domestic product*. January.

U.S. DOC. 2008. Electric Lighting Fixtures and Lamps 2007. U.S. Imports for Consumption. Washington D.C., U.S. Department of Commerce, Bureau of the Census, Prepared by the Office of Trade and Industry Information.

U.S. DOE (United States Department of Energy). 1995. *Residential energy consumption survey 1993: Housing Characteristics*. DOE/EIA-0314(93). Energy Information Administration, Office of Energy Markets and End Use. Washington, D.C. June.

U.S. DOE. 1996a. *Annual energy outlook 1996 with projections to 2015*. DOE/EIA-0383(96). Energy Information Administration. Washington, D.C. January.

U.S. DOE. 1996b. *Annual energy outlook 1997 with projections to 2015*. DOE/EIA-0383(97). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 1997. *Annual energy outlook 1998 with projections to 2020*. DOE/EIA-0383(98). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 1998. *Annual energy outlook 1999 with projections to 2020*. DOE/EIA-0383(99). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 1999. *Annual energy outlook 2000 with projections to 2020*. DOE/EIA-0383(2000). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 2000. *Annual energy outlook 2001 with projections to 2020*. DOE/EIA-0383(2001). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 2001. *Annual energy outlook 2002 with projections to 2020*. DOE/EIA-0383(2002). Energy Information Administration. Washington, D.C. December.

U.S. DOE. 2003a. *Annual energy outlook 2003 with projections to 2025*. DOE/EIA-0383(2003). Energy Information Administration. Washington, D.C. January.

U.S. DOE. 2003b. *A Look at Residential Energy Consumption in 2001*. Washington DC: U.S. Department of Energy: Energy Information Administration.

US DOE. 2004. *Residential Energy Consumption Survey 2001: Housing Characteristics.* DOE/EIA-0314(01). Energy Information Administration, Office of Energy Markets and End Use. Washington, D.C.

US DOE. 2005. *Annual Energy Outlook 2005 with Projections to 2025.* DOE/EIA-0383(2005). Energy Information Administration. Washington, D.C. February.

US DOE. 2006. *Annual Energy Outlook 2006 with Projections to 2025.* DOE/EIA-0383(2006). Energy Information Administration. Washington, D.C. February.

US DOE. 2007. *Annual Energy Outlook 2007 with Projections to 2030.* DOE/EIA-0383(2007). Energy Information Administration. Washington, D.C. February.

US DOE. 2008. *Annual Energy Outlook 2008 with Projections to 2030.* DOE/EIA-0383(2008). Energy Information Administration. Washington, D.C. June.

U.S. EPA (United States Environmental Protection Agency). 2003a. Commercial Steam Cookers. Energy Star Program Requirements. Washington D.C., Climate Protection Partnership Programs, Energy Star Product Labeling Branch: 1–4.

U.S. EPA. 2003b. Commercial Fryers. Energy Star Program Requirements. Washington D.C., Climate Protection Partnership Programs, Energy Star Product Labeling Branch: 1–4.

U.S. EPA. 2006. Energy Star Qualified Televisions. Retrieved February 14, 2006, from U.S. Environmental Protection Agency, Climate Protection Partnerships, Energy Star.

U.S. EPA. 2007a. *Energy Star and other climate protection partnerships 2006 annual report*. Washington, D.C. October.

U.S. EPA. 2007b. *Estimating Avoided Carbon Emissions from US Environmental Protection Agency, Climate Protection Partnership Programs*. Prepared by Ashley King, Environmental Scientist (U.S. EPA). Washington D.C. July 26.

U.S. EPA. 2007c. Manufacturer Power Consumption Test Dataset for Energy Star Computers Specification Revision. Washington D.C., Climate Protection Partnerships, Energy Star Product Labeling Branch.

U.S. EPA. 2008a. *Maintaining the value of Energy Star 2007 Report*. Washington, D.C.

Vine, E., and D. Fielding. "An evaluation of residential CFL hours-of-use methodologies and estimates: Recommendations for evaluators and program managers." *Energy and Buildings* 38 (2006): 1388–1394.

Vorsatz, D., L. Shown, J. Koomey, M. Moezzi, A. Denver, and B. Atkinson. 1997. *Lighting Market Sourcebook for the U.S.* LBNL-39102. Berkeley, California: Lawrence Berkeley National Laboratory. December.

Warren, K. 1996. Reference Case Energy Star Market Penetration for Thermostats. Farmington, Connecticut. Carrier, Inc.

Webber, Carrie. 1999. LBNL Field Measurement of Audio Equipment. Prepared for the U.S. Environmental Protection Agency: Washington D.C. Results contained in spreadsheet AudSav16.xls (maintained by LBNL).

Webber, C. A. 2001. List of qualifying Energy Star copiers from the Star Database. (Spreadsheet, EStar_Copier_list_Feb01.xls).

Webber, C. 2003. Compilation of FSEC, LBNL, UCB Telephony Field Power Measurements. Lawrence Berkeley National Laboratory.

Webber, C. A. 2004. List of qualifying Energy Star MFDs from the Star Database. (Spreadsheet, Star_DB_Copier_and_MFD_040120_5.xls).

Webber, C. 2007. Potential Energy Savings for External Power Supplies. (Spreadsheet, CCAP-PS 070713). Lawrence Berkeley National Laboratory.

Webber, C., J. Roberson, R. Brown, C. Payne, B. Nordman, and J. Koomey. 2001. *Field Surveys of Office Equipment Operating Patterns.* LBNL-46930. Berkeley, California: Lawrence Berkeley National Laboratory. September.

Wesphalen, D., R. Zogg, et al. 1996. Energy Savings Potential for Commercial Refrigeration. Cambridge, Massachussets: Arthur D. Little. 1–19.

Zabrowski, D. 2003. Reference Case Baseline Assumptions for Energy Star Food Service Equipment. San Francisco, California: Fisher Nickel, Inc. (Food Service Technology Center). Prepared for U.S. EPA Energy Star: 5.

Zabrowski, D. 2008. Life Cycle and Energy Cost Calculator for Food Service Equipment. San Francisco, California: Fisher Nickel, Inc (Food Service Technology Center). 1–5.

Zogg, R., and D. Alberino. 1998. *Electricity Consumption by Small End Uses in Residential Buildings*. Cambridge, Massachussets: Arthur D. Little.

11. Acronyms and Abbreviations

AFUE	annual fuel utilization efficiency
AHAM	Association of Home Appliance Manufacturers
ASHP	air source heat pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
REF UEC	reference case unit energy consumption
Btu	British thermal unit
CAC	central air conditioner
CADR	clean air delivery rate
CEC	California Energy Commission
CFL	compact fluorescent lamp
CFM	cubic foot per minute
C&I	commercial & industrial (transformer)
CLF	conservation load factor
COP	coefficient of performance
CPU	central processing unit
CRT	cathode-ray tube (display)
DLS	decorative light string
DOCSIS	data over cable service interface specification
DSL	digital subscriber line
DVD	digital versatile disc
DVR	digital video recorder
DSS	direct sequence spread spectrum (a type of cordless telephone technology)
DTA	digital television adapter
EER	energy efficiency ratio
EF	energy factor
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 2005
EPS	external power supply
FSTC	Food Service Technology Center
GJ	gigajoule
GPR	gallons per rack (commercial dishwasher)
HD	high definition
HDMI	high definition multimedia interface
HFHC	hot food holding cabinets
HP	heat pump
HSPF	heating seasonal performance factor
HTIB	home theater in a box
HVAC	heating, ventilation, and air condition
IM	ice maker
IMH	ice making head
IPTV	internet protocol television

IPLV	integrated part load value
IT	information technology
kVA	kilovolt-ampere
kWh	kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
LAN	Local Area Network
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MFD	Multi-Functional Device
MTBF	mean time between failures
NAECA	National Appliance Energy Conservation Act
NAFEM	National Food Manufacturing Association
NEMA	National Electrical Manufacturers Association
NTIA	National Telecommunications and Information Administration
OTA	over the air (concerning television signals)
ORNL	Oakridge National Laboratory
PDA	Personal Digital Assistant
PDP	plasma display panel
PECI	Portland Energy Conservation Incorporated
PM	power management
PSIP	Program and System Information Protocol
PVR	personal video recorder
RCU	remote condensing unit (ice maker)
RECS	Residential Energy Consumption Survey
SCU	self-contained unit (ice makers where the ice-making mechanism and storage are separate)
SEER	seasonal energy efficiency ratio
SST	Spread Spectrum Technology
STB	Set-top boxes (general term to cover consumer electronic device that receives and decodes digital video signals)
TAD	telephone answering device
TPU	Tacoma Public Utilities
TEC	total energy consumption
UEC	unit energy consumption
UES	unit energy savings (REF UEC minus Energy Star UEC for products)
Vb	battery voltage
VCR	video cassette recorder
VGA	video graphics array
W	watts

12. Glossary

Market Transformation - lasting change in a product market as a result of Energy Star's strategic intervention targeted at removing identified barriers and accelerating the adoption of cost-effective energy efficient models as a matter of standard manufacture and consumer purchase decision.

Stock – the installed base of units in the U.S. building sector.

Reference UEC – represents the average annual unit energy consumption of units that do not meet the Energy Star criteria. This is abbreviated in report as REF.

Non-Energy Star UEC – represents the average annual unit energy consumption of units that do not participate in the Energy Star program.

Energy Star UEC – represents annual unit energy consumption of units participating in the Energy Star program. The annual UEC may be either the average UEC of Energy Star qualified units or the maximum allowable UEC under the specification.

Energy Star UES – represents annual unit energy consumption of units participating in the Energy Star program. The annual UEC may be either the average UEC of Energy Star qualified units or the maximum allowable UEC under the specification.

Free rider – represents Energy Star unit sales that are not attributed to EPA Energy Star.