Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program

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DISCLAIMER

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Abstract

ENERGY STAR is a voluntary energy efficiency-labeling program operated jointly by the United States Department of Energy and the United States Environmental Protection Agency (US EPA). 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 committed stakeholders. Through 2006, US EPA'S ENERGY STAR labeled products saved 4.8 EJ of primary energy and avoided 82 Tg C equivalent. We project that US EPA'S ENERGY STAR labeled products will save 12.8 EJ and avoid 203 Tg C equivalent over the period 2007-2015. A sensitivity analysis examining two key inputs (carbon factor and ENERGY STAR unit sales) bounds the best estimate of carbon avoided between 54 Tg C and 107 Tg C (1993 to 2006) and between 132 Tg C and 278 Tg C (2007 to 2015).

1. Introduction and Study Objectives

ENERGY STAR is a voluntary labeling program operated jointly by the U.S. Department of Energy (US DOE) and the U.S. Environmental Protection Agency (US EPA). US DOE and US 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, US DOE and US EPA reduce air pollution and greenhouse gases associated with the consumption of energy. For a more detailed description of the ENERGY STAR program, refer to McWhinney et al. (2005) and Brown et al. (2002).

Webber et al. (2000) first published an overview of savings for the United States Environmental Protection Agency's (US EPA) ENERGY STAR labeled products. Since the 2000 publication, US EPA has added numerous new product types to its program and revised eligibility requirements for key product categories. Several important methodological changes to the savings analysis have been made to more accurately quantify program impacts. In this article, we address the following questions for US EPA ENERGY STAR labeled product types included in our analysis:

- How are ENERGY STAR impacts quantified?
- What are ENERGY STAR achievements?
- What are the limitations to our method?

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

2. Study Scope

ENERGY STAR consists of four programmatic areas: products, buildings and industrial plants, home performance, and new homes. Complete descriptions of these program areas can be found at www.energystar.gov. This article focuses only on labeled products such as office equipment, appliances, and electronics that are administered by US EPA. This article does not cover savings for buildings and industrial plants, home performance, new homes, or labeled products administered by US DOE. The methodologies for quantifying savings for these program segments are significantly different than the methodology outlined in this paper (for US EPA labeled products). We cannot address these additional methodologies and results with the necessary detail within the scope of this paper. See Horowitz (2001, 2004, 2007) for a complete summary of program impacts for ENERGY STAR Buildings. See US EPA (2006) for a summary of program impacts for ENERGY STAR home performance, industrial plants, and new homes.

ENERGY STAR product types are shown in **Table 1**. For each product type, we list the program start year and the dates for subsequent specification revisions. All product types included in this analysis are either new ENERGY STAR products or have had eligibility requirements revised since Webber et al. (2000). Since 2000, US EPA developed ENERGY STAR criteria for the following new product types:

- battery charging systems
- bottled water coolers
- ceiling fans
- commercial fryers
- commercial hot food holding cabinets

- commercial refrigerators and freezers
- commercial steam cookers
- dehumidifiers
- digital TV adapters
- external power supplies
- light commercial HVAC
- refrigerated beverage vending machines
- room air cleaners
- set-top boxes
- telephony
- traffic lights
- ventilation fans

The following existing product specifications were revised since 2000:

- air source heat pumps
- audio equipment and DVD
- boilers
- central air conditioners
- computers
- exit signs
- furnaces
- geothermal heat pumps
- imaging equipment
- residential light fixtures
- roofing,
- televisions and videocassette recorders

ENERGY STAR specifications were suspended for the following product types:

- programmable thermostats
- set-top boxes
- traffic signals
- transformers

Table 1. Summary of ENERGY STAR products

	Specification Effective Dates	
	Original Specification	Specification Revision Dates
Product types included in analysis		
Audio and DVD[1, 2]	1999	2003
Battery charging systems	2006	
Boilers	1996	1998, 2002
CAC/ASHP[2]	1995	2002, 2006, 2009
Ceiling fans	2002	2003, 2006
Commercial fryers	2003	
Commercial hot food holding cabinets	2003	
Commercial solid door refrigerators and freezers	2001	
Commercial steam cookers	2003	
Computers	1992	1995, 1999, 2000, 2007, 2009
Copiers	1995	1997, 1999, 2007, 2009
Dehumidifiers	2001	2006, 2007, 2008
Digital TV Adapters	2007	
Exit signs	1996	1999, 2004
External power adapters	2005	
Facsimile	1995	1995, 2000, 2001, 2007, 2009
Furnaces	1995	2006
Geothermal HP[2]	1995	2001
Light commercial HVAC[2]	2002	2004
Monitors	1992	1995, 1998, 1999, 2005, 2006
Multifunction devices	1997	1999, 2007, 2009
Printers	1993	1995, 2000, 2001, 2007, 2009
Programmable thermostats[3]	1995	*2008
Residential light fixtures	1997	2001, 2002, 2003, 2005
Roof products	1999	2005
Room air cleaners	2004	
Scanners	1997	2007, 2009
Set-top boxes[3]	2001	*2005
Telephony	2002	2004, 2006
Televisions/VCRs[2]	1998	2002, 2004, 2005
Traffic signals[3]	2000	2003, *2007
Transformers[3]	1995	*2007
Vending machines	2004	2006, 2007
Ventilation fans	2001	2003
Water coolers	2000	2004
Product types not included in analysis[4, 5]		
Buildings and industrial plants[6]	1991	1995, 1999, 2000, 2001, 2002, 2004, 2006
CFLs[2]	1999	2001, 2004
Clothes washers	1997	2001, 2004, 2007
Dishwashers	1996	2001, 2007
Home performance	2000	2002
Insulation[7]	1995	*2002
New homes	1995	1997, 2006
Refrigerators and freezers	1996	2001, 2003, 2004, 2008
Room air conditioners	1996	2000, 2003, 2005
Windows, doors, and skylight	1997	2003, 2005

1) Audio includes CDs, mini-systems, audio separates, and home theater in a box.
2) CAC =central air conditioning, ASHP = air source heat pump, HP = heat pump, DVD = digital versatile disc, CFL = compact fluorescent lamp, HVAC = heating ventilation and air conditioning, VCR=video cassette recorder.
3) Specification revisions that resulted in program suspension are indicated with an "*"

4) CFLs, clothes washers, dishwashers, refrigerators and freezers, room air conditioners, windows/doors/skylights are US DOE products and are not covered in this paper.
5) Buildings and Industrial Plants, New Homes, and Home Performance programs are administered by US EPA but are not included due to a different program benefits methodology.
6) Changes to ENERGY STAR buildings and industrial plants reflect building types or manufacturing sectors added to the program.
7) Insulation specification revised in 2002 and insulation incorporated into Home Performance with ENERGY STAR.

Full eligibility requirements for each product can be found at www.energystar.gov.

Our study 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. In this paper, we present analysis results for energy savings, carbon savings and monetary savings over the period 1993-2015.

3. Program Attribution

Numerous supporting stakeholders including utilities, regional energy partnerships, energy consortiums, and non-profit organizations leverage the ENERGY STAR program nationally. All stakeholders work towards advancing ENERGY STAR goals, improving ENERGY STAR consumer awareness, and promoting the sales of ENERGY STAR products. This paper provides a top-level summary of national savings achieved by US EPA 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 Overview

We employ a bottom-up methodology for quantifying savings for US EPA ENERGY STAR labeled products. 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 US EPA'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 US EPA 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 inaccuracy 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. 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 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 US DOE's Energy Information Administration (US 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, including residential heating and cooling equipment, televisions and set-top boxes, home computers, commercial office equipment, and lighting.

4.2 Methodology Summary

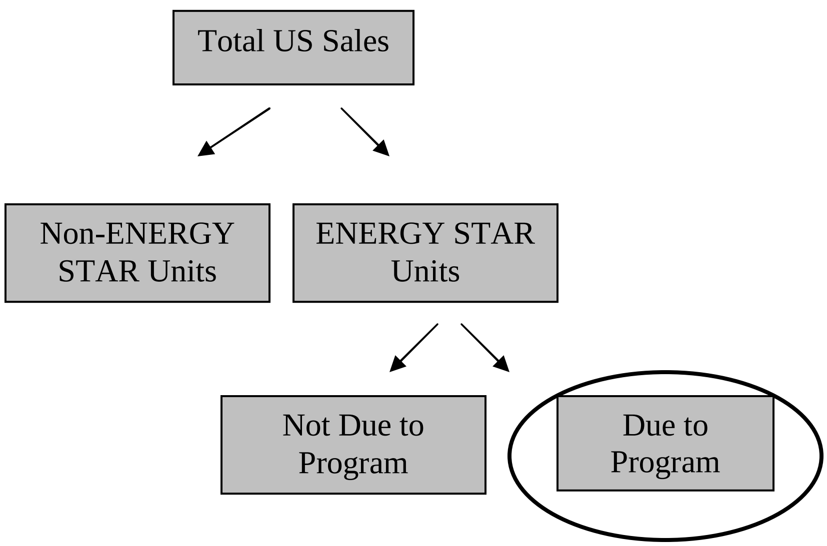
We begin the analysis by segmenting sales of each product type into non-ENERGY STAR and ENERGY STAR units. Manufacturer partners report ENERGY STAR unit sales to US EPA each calendar year[1]. Non-ENERGY STAR unit sales are estimated as the difference between total US unit sales obtained from industry reports and ENERGY STAR unit sales.

Sales of ENERGY STAR units are further divided into ENERGY STAR unit sales attributed to US EPA program efforts and ENERGY STAR unit sales not attributed to US EPA program efforts. At each product launch, we set the ENERGY STAR units not attributed to US EPA equal to the market share of products that meet the final ENERGY STAR performance level at the time of US EPA's initial product development/market transformation efforts. This initial ENERGY STAR program penetration is calculated using the energy consumption test data collected by US EPA at the start of its product development effort. To estimate the initial ENERGY STAR market share, we divide the total number of models in the dataset by the number of models in the dataset that meet the final ENERGY STAR performance levels. ENERGY

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

STAR unit sales attributed to the program are calculated as the total US ENERGY STAR unit sales in any given year minus ENERGY STAR unit sales not attributed to the program. ENERGY STAR savings include only the savings for ENERGY STAR units directly attributed to the program. **Figure 1** illustrates the sales segmentation.

Figure 1. Market segmentation of ENERGY STAR products [products in circle accrue savings for the program]



We next estimate unit energy consumptions (UEC) for both non-ENERGY STAR and ENERGY STAR units. Our BAU forecast is comprised of standard efficiency unit sales (representing units that do not meet the ENERGY STAR requirement) and high efficiency non-ENERGY STAR unit sales (representing units that meet or exceed ENERGY STAR requirement but are not attributable to the program). The BAU is characterized both by a UEC and a market share for each segment. BAU efficiency improvements can be modeled directly as a change in the UEC of either of these segments. We can also model BAU efficiency improvements as a shift over time from standard efficiency 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 BAU 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 BAU 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 US DOE shown in **Table 2**. Energy bill savings are discounted at a 4 percent real discount rate. Carbon emissions reductions are calculated from energy savings using year-by-year carbon emissions factors. For electricity, we use EPA's national average marginal carbon factor, which is derived from models used as part of the US government's reporting requirements under the U.N. Framework Convention on Climate Change and historical emissions data from US 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®) (US EPA 2007). Carbon factors for natural gas and oil are assumed to be constant throughout the period at 13.65 kg C/GJ for natural gas and 18.72 kg C/GJ for oil. **Equation 1** summarizes our calculation methodology for estimating ENERGY STAR savings for a single product type in year t:

Equation 1.

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

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

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

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 GJ)

L = product lifetime

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

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

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

Table 2. Best Estimate Energy Prices and Carbon Factors by Year (2006 dollars)

Year	Cmcl. Elec Price $/kWh[2]	Res. Electricity Price $/kWh[2]	Cmcl. Gas Price $/GJ[2]	Res. Gas Price $/GJ[2]	Oil Price $/GJ[2]	Price Sources, US DOE [3]	Carbon Emissions Factor for Electricity kg C/kWh[1, 4]	Electric Heat Rate kJ/kWh	Electric Heat Rate Source, US DOE [3]
1993	0.102	0.109	6.23	7.40	8.15	1996a	0.203	11,625	1996a
1994	0.101	0.109	6.52	7.63	7.75	1996b	0.203	11,551	1996b
1995	0.094	0.105	5.94	7.11	7.49	1997	0.203	11,573	1997
1996	0.093	0.103	6.17	7.24	8.28	1998	0.203	11,464	1998
1997	0.092	0.101	6.51	7.79	8.14	1999	0.203	11,582	1999
1998	0.090	0.098	6.15	7.58	7.02	2000	0.203	11,490	2000
1999	0.085	0.096	5.87	7.32	7.03	2001	0.203	11,377	2001
2000	0.085	0.095	7.13	8.33	10.39	2003	0.203	11,796	2003
2001	0.089	0.097	8.91	10.06	9.60	2003	0.203	11,636	2003
2002	0.087	0.094	6.84	8.08	8.65	2005	0.203	11,613	2005
2003	0.086	0.095	8.30	9.48	9.90	2006	0.203	11,602	2006
2004	0.086	0.095	9.17	10.46	12.58	2007	0.203	11,554	2007
2005	0.089	0.097	10.93	12.13	14.37	2007	0.203	11,448	2007
2010	0.086	0.095	9.11	10.71	14.51	2007	0.180	11,349	2007
2015	0.082	0.091	8.27	9.99	12.29	2007	0.180	11,184	2007

1) Carbon coefficients for natural gas and oil are assumed to be constant throughout the period at 13.65 kg C/GJ for natural gas and 18.72 kg C/GJ for oil. Carbon emissions factors for electricity are marginal, not average.
2) All prices have been converted to 2006 dollars using implicit GDP deflators from the US Department of Commerce (2007).
3) US DOE refers to US 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 Section 7.0.
4) Carbon emission factors (1993-2005) are from the Cadmus Group (1998), carbon emission factors 2010 and 2015 are from US EPA (2007). Note that US EPA more recently updated the 2010 and 2015 carbon emission factor to 0.190 kg C/kWh, which is not reflected in this paper.
5) Cmcl = commercial; Res = residential

US EPA 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. **Table 3** illustrates a hypothetical application of this methodology. ENERGY STAR realizes savings for the cohort of products until it is completely phased out by products meeting the revised ENERGY STAR criteria. This cohort realizes savings at a UES equivalent to 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, energy consumption test data for non-qualified models submitted by manufacturers to US EPA during a subsequent specification revision support this assumption. In reference to our general program savings equation, the market transformation effect means that in any given year n, the number of units sold for a single product type that will accrue program savings (X) is equal to:

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

and the average UES in any given year n, is equal to:

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

where t is the current Tier of the ENERGY STAR specification in year n.

Table 3. ENERGY STAR Market Transformation Methodology

	2002	2003	2004	2005	2006	2007	2008
ENERGY STAR Sales - Tier 1[1]	300	440	600	340	180	0	0
ENERGY STAR Sales - Tier 2				260	420	600	800
Total ENERGY STAR Sales[2]	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 Saved, 1 Years Sales (kWh/yr)	15,000	22,000	30,000	37,800	42,600	48,000	64,000
Total Yearly Energy Saved (kWh/yr)	15,000	37,000	67,000	104,800	147,400	195,400	259,400

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 II specification. We calculate that 260 units (600-340) were sold in 2005 that continued to meet Tier I levels. We assume that the 260 units accrue savings equivalent to 50 kWh/year (the UES for Tier 1). This methodology is applied until 2007 when ENERGY STAR units shipped under Tier II is equivalent to ENERGY STAR units shipped under Tier I (in 2004).

4.3 Product Category Overview

Our analysis groups ENERGY STAR product types into the following categories: office equipment, consumer electronics, heating/ventilation/air conditioning (HVAC), lighting, residential appliances, commercial appliances, and other. We summarize our methodology for each product category below.

4.3.1 Office Equipment

Office equipment includes computers, copiers, facsimile machines, monitors, multifunction devices (MFD), printers, and scanners. ENERGY STAR computers and monitors incorporate a sleep mode in which a product enters a low power mode after a period of inactivity. ENERGY STAR computers and monitors must meet maximum power requirements in sleep mode, standby mode and on or idle mode. ENERGY STAR imaging equipment must meet either a maximum total energy consumption (TEC) requirement expressed as kWh/week or maximum operational mode power requirements (sleep and standby) depending on a product's marking technology and size format[2].

We model residential and office settings separately due to different usage patterns. Commercial operating patterns are derived from equipment audits at various locations that provide time spent in each operating mode, nighttime turn-off rates, and power management success rates (Piette et al. 1995; Nordman et al. 1998; Webber et al. 2001; Roberson et al. 2004). Operating patterns for residential computers are derived from hours-of-use monitoring for a large sample of residential computer users (Media Metrix 2001). Operating patterns for residential monitors, MFDs, printers, and scanners are from field measurement data for a sample of California homes (Porter et al. 2006).

We calculate the BAU and ENERGY STAR UEC by multiplying the time spent in each power mode by the power consumption in each mode, then summing over all power modes. Low power savings are only realized for ENERGY STAR products that are successfully power managing (Roberson et al. 2004).

4.3.2 Consumer Electronics

Consumer electronics include audio equipment and DVDs, battery charging systems, external power supplies, set-top boxes, telephony, TVs, and VCRs. ENERGY STAR for audio/DVD, set-top boxes, telephony, and TV/VCR products focuses on reducing the power consumption of a device in its standby mode. Savings are assumed to accrue in both active and standby mode since efficiency improvements to achieve standby savings (like remote control and memory) reduce power whether the device is in

[2] US EPA defines the on/active mode for monitors as the state in which the unit is connected to the power source and producing an image. US EPA defines the idle mode for computers as the state in which the operating system and other software have completed loading, the machine is not asleep and activity is limited to those basic applications that the system starts by default. Standby mode refers to a product's lowest power state.

on or standby mode. We estimate BAU and ENERGY STAR UECs by multiplying the time spent in each power mode by the power consumption in each mode, then summing over all power modes. Power consumption and usage patterns are derived from Floyd and Webber (1998); Nordman and McMahon (2004); Horowitz et al. (2005); Roth and McKenney (2007); and Porter et al. (2006).

ENERGY STAR external power adapters must meet efficiency criteria in both active and no-load modes. ENERGY STAR battery charging system must meet a non-active energy ratio requirement, which is the non-active energy of a battery charging system divided by the energy deliverable by the battery under a known discharge condition. Calwell (2003) provides BAU and ENERGY STAR UECs for external power adapters. BAU and ENERGY STAR UECs for battery charging systems are derived from Webber et al. (2006).

4.3.3 Residential HVAC

The HVAC program covers air-source heat pumps (ASHP), boilers (gas and oil), central air conditioners (CAC), furnaces (gas and oil), geothermal heat pumps, and programmable thermostats. For heating and cooling equipment, ENERGY STAR eligibility is based solely on efficiency, measured by standard test procedures such as the average fuel utilization efficiency (AFUE) or the seasonal energy efficiency ratio (SEER). Programmable thermostats qualify for the ENERGY STAR label by automating the set back of thermostats at times determined by the building occupant. Savings for HVAC products with an applicable minimum federal efficiency standard (ASHP, CAC, furnaces, and boilers) are calculated by improving the unit efficiency from the federal minimum level to the ENERGY STAR level.

We derive the baseline UECs using household level data from the 1993 Residential Energy Consumption survey (US DOE 1995) [3]. We model the baseline UEC using equipment efficiency equal to the federal minimum efficiency standard where applicable. The UECs for ENERGY STAR equipment are similarly modeled but assume ENERGY STAR equipment efficiency levels. Regional UECs are then aggregated to a national average. Our savings estimates do not include improving the quality of equipment installation, appropriately sizing equipment, and/or air sealing within the home. These improvements are a part of the Home Performance with ENERGY STAR program and are accounted for separately by US EPA.

To avoid double counting savings, we analyze programmable thermostats in conjunction with HVAC equipment. We assume that HVAC equipment is chosen first and therefore ENERGY STAR HVAC receives its full measure of savings. Programmable thermostat savings are calculated from a forecast of HVAC energy use that takes into account the increasing market penetration of ENERGY STAR HVAC and any changes to the federal minimum efficiency standard.

To account for savings uncertainty related to programmable thermostats, we make a conservative estimate of the number of ENERGY STAR programmable thermostat units that successfully realize savings. We adjust our total ENERGY STAR programmable thermostat unit sales to account for the following factors: sales represent manual thermostat replacements only (70% of total ENERGY STAR unit sales), we assume US EPA is credited with only 40% of ENERGY STAR units that replace manual

[3] The Residential Energy Consumption Survey (RECS) is a national multistage probability sample survey that the US EIA conducts every three years. RECS gathers data primarily by means of personal interviews with householders and a mail survey of those household's energy suppliers. The 1993 RECS sample included more than seven thousand households.

thermostats, we assume that only 44% of sales credited to US EPA are installed in homes that did not previously setback the thermostat manually (US DOE, 2004), and we assume that only 70% of unit sales to homes that did not previously setback manually are properly programmed and successfully achieving energy savings (US DOE, 2004). Once the four adjustment factors are applied, we credit US EPA savings to less than 10% of total ENERGY STAR programmable thermostat unit sales. We assume a 14% reduction in household heating consumption[4]. We do not assume any cooling savings due to the limited data available to support verified savings. Beginning in 2010, we assume no additional sales of ENERGY STAR units due to the discontinuation of the ENERGY STAR programmable thermostat specification.

While ENERGY STAR New Homes are not covered in this analysis, the effects of ENERGY STAR New Homes are taken into account when estimating savings for ENERGY STAR HVAC equipment. Since ENERGY STAR HVAC equipment is typically part of an ENERGY STAR New Home and counted toward its savings, sales of ENERGY STAR HVAC equipment are first allocated to the New Homes program and the remaining ENERGY STAR equipment sales are accounted for in this analysis.

4.3.4 Lighting

Lighting includes exit signs, residential fixtures (indoor and outdoor), and traffic signals. Through 2005, savings for exit signs are calculated from a BAU UEC that is a market share weighted average across incandescent, CFL, and non-ENERGY STAR LED energy consumption (Suozzo and Nadel, 1998). From 2006 onward, the BAU UEC is set

[4] Based on RLW Analytics (2007), which showed a household energy savings of approximately 8% per thermostat for homes in New England (RLW 2007). We adjusted the per household savings by the fraction of household energy consumption due to heating for New England (58%) and arrive at a 14% reduction in heating consumption.

equivalent to the federal minimum efficiency standard. ENERGY STAR assumes an average power of five Watts (W) and an annual operating time of 8,760 hours.

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 et al. 2005). Since ENERGY STAR fixtures require pin-based lamps, we assume savings accrue over the lifetime of the fixture (20 years). Savings for outdoor fixtures assume replacing a 109 W incandescent lamp with a 36 W fluorescent lamp (Vorsatz et al. 1997). We assume a daily operating time of five hours (Vine et al. 2005).

Savings for ENERGY STAR traffic signals are based on stock replacement rather than ENERGY STAR unit sales since retrofits are the primary market driver. Red and green traffic signals are modeled separately due to differences in cost effectiveness. Yellow (amber) signals are not analyzed because of their very short operating times. Suozzo (1998) and Caltrans (1999) provide UECs for each signal type analyzed. The ENERGY STAR specification for traffic signals was suspended in 2007 due to a new federal minimum efficiency standard and we assume no additional savings throughout the forecast period.

4.3.5 Residential Appliances

Residential appliances include ceiling fans, dehumidifiers, room air cleaners, and ventilation fans. Ceiling fans include fan only units, fans with lights, and light kit only. We separately model fans located in the southern region versus fans located elsewhere in the US due to the different operating times as summarized below (52% of installed stock in the south and 48% of installed stock elsewhere (US DOE 2004)). Ceiling fan UEC data are taken from Calwell and Horowitz (2001) and are based on a BAU 34 W fan with 180 W of lighting. The ENERGY STAR case assumes a 31 W fan with 60 W of lighting. We assume a daily operating time for the fan of 9 hours in the south and three hours elsewhere. We assume the lighting is operated three hours per day.

ENERGY STAR dehumidifiers must meet energy performance requirements specified in terms of kWh of energy used per liter of water removed from the air. Through 2007, the BAU UEC is derived from energy consumption test data collected by the Canadian Standards Association (CSA) in conjunction with Natural Resources Canada (McWhinney et al. 2005). From 2008 onward, the BAU UEC is equivalent to the applicable federal minimum efficiency standard. The ENERGY STAR UEC represents the minimum efficiency program requirements for an average equipment capacity. We assume annual operating time of 1,620 hours (Cadmus Group 1999).

ENERGY STAR room air cleaners must meet energy performance requirements that are specified in terms of volume of air cleaned per minute (defined as clean air delivery rate or CADR) per W. We analyze the following CADR bins (m^3/min): 1.4-2.8, 2.8-4.2, 4.2-5.7, 5.7-7.1, greater than 7.1. BAU wattage is derived from manufacturer power consumption test data for individual product models. ENERGY STAR wattages are extrapolated by dividing the average CADR per CADR bin by the ENERGY STAR efficiency criteria (2 CADR per watt). Our savings assume that room air cleaners are operated continuously.

ENERGY STAR ventilation fans include rangehood fans and bathroom and utility room fans. We assume a daily operating time of one hour. The BAU UECs are from Cadmus (2000a) and ENERGY STAR UECs reflect the minimum program requirements.

3.3.6 Commercial Appliances

Commercial appliances include bottled water coolers, commercial fryers, commercial hot food holding cabinets, commercial refrigerators and freezers, commercial steamers, and refrigerated beverage vending machines.

ENERGY STAR bottled water coolers include hot and cold units and cold only units. ENERGY STAR focuses on reducing a unit's standby energy consumption and specification requirements are expressed as a maximum standby energy consumption requirement per day. Our BAU and ENERGY STAR UECs are taken from engineering testing conducted by the Cadmus Group, Inc (2000b).

The specifications for fryers and steamers include a cooking efficiency (the quantity of energy input into the food expressed as a percent of the energy input to the appliance) and an idle rate, expressed in Btu/hr (gas appliances) or watts (electric). Hot food holding cabinets have only an idle energy rate requirement, expressed in watts per cubic foot. UECs for commercial cooking equipment are obtained from the Food Service Technology Center (FSTC 2007).

Data for commercial refrigerators and freezers are taken from FSTC (2007). Although the program covers refrigerators, freezers, and ice cream freezers, we only model solid door refrigerators and freezers due to insufficient data regarding ice cream freezers. Efficiencies are expressed as kWh per day. From 2010 onward, the BAU UEC is set equal to the federal minimum efficiency standard.

Refrigerated beverage vending machines include both newly manufactured and refurbished units. Units are modeled by the following can capacities: less than 500, 500-600, 600-700, and greater than 800. Baseline UECs are taken from product energy consumption test data gathered by Horowitz (2002). ENERGY STAR UECs are calculated as the required percentage reduction in energy consumption from the current Canadian minimum efficiency standard. UECs also include a standby consumption and an enabling rate for ENERGY STAR units that enter a low power mode after a period of inactivity.

4.3.7 Other Products

Other ENERGY STAR products include transformers (commercial/industrial and utility) and roofing (residential and commercial). Commercial/industrial transformers assume a BAU UEC for a unit with a 45 kVA rating, a load factor of 35% and a 97.3% efficiency (Suozzo and Nadel, 1998). ENERGY STAR requires an efficiency of 98% based on the specification average of single phase and three phase transformers. Utility transformers assume a BAU UEC for a unit with a 25 kVA rating, a load factor of 30%, and an efficiency of 98.5%. ENERGY STAR requires an efficiency of 98.65% (ORNL 1996). The ENERGY STAR specification for transformers was suspended in 2007 due to a new federal minimum efficiency standard and we do not assume any additional savings throughout the forecast period.

ENERGY STAR roofing has a higher reflectivity than standard roofing in order to reduce heat gains into the building and the resulting cooling load. UES for ENERGY

STAR roofing are based on a US average derived from a study of 11 metropolitan areas including: Atlanta, Dallas, Chicago, Houston, Los Angeles, Miami, New Orleans, New York, Philadelphia, Phoenix, and Washington DC. Savings are expressed in primary energy and include cooling savings and increased energy use during the heating season (Konopacki et al. 1997).

5.0 Results

5.1 Savings for US EPA ENERGY STAR labeled products

Through 2006, US EPA's ENERGY STAR labeled products saved 4.8 EJ of primary energy, $47 billion dollars in energy bills (discounted at 4%), and avoided 82 Tg C equivalent (eq.) through its voluntary program efforts (**Table 4**). Although US EPA ENERGY STAR labeled products encompass over forty product types, only six of those product types accounted for 70% of all ENERGY STAR carbon reductions achieved to date. Those product types are as follows (ranked by total carbon avoided through 2006):

- Monitors: 33.4 Tg C (41% of total)
- Printers: 10.6 Tg C (13% of total)
- Residential light fixtures: 4.0 Tg C (5% of total)
- TVs: 3.9 Tg C (4% of total)
- Furnaces: 3.5 Tg C (4% of total)
- Computers: 3.2 Tg C (4% of total)

Table 4. Savings for US EPA ENERGY STAR Labeled Products (1993-2015)

Savings Analysis Period		Achieved Savings through 2006[1]			Projected Savings 2007-2015[1]		
Program		Primary Energy Savings[2]	Disc Energy Bill Savings[3]	Carbon Avoided[4]	Primary Energy Savings[2]	Disc Energy Bill Savings[3]	Carbon Avoided[4]
		PJ	Million $2006	Tg C eq.	PJ	Million $2006	Tg C eq.
Office Equipment	- Computers	185	$1,759	3.20	1,362	$8,923	21.76
	- Monitors	1,915	$18,681	33.41	2,101	$14,227	33.47
	- Fax	47	$494	0.82	45	$319	0.71
	- Copier	149	$1,408	2.60	397	$2,640	6.33
	-Multifunction Device	167	$1,532	2.90	440	$2,803	7.03
	- Scanner	53	$508	0.92	45	$310	0.71
	- Printer	606	$6,106	10.56	1,559	$10,395	24.87
	Subtotal	**3,122**	**$30,488**	**54.41**	**5,948**	**$39,617**	**94.89**
Consumer Electronics	- TVs	227	$2,222	3.92	1,126	$8,171	17.97
	-VCRs	91	$914	1.58	77	$577	1.22
	-TV/VCR/DVD	76	$749	1.32	148	$1,108	2.36
	-DVD Player	44	$425	0.76	144	$1,062	2.29
	-Audio Equipment	49	$480	0.85	101	$755	1.60
	-Telephony	29	$279	0.50	150	$1,087	2.39
	-Set-top Box	0	$3	0.00	37	$261	0.59
	-External Power Supplies	8	$75	0.14	319	$2,173	5.09
	-Battery Charging Systems	0	$0	0.00	0	$2	0.00
	Subtotal	**525**	**$5,147**	**9.09**	**2,102**	**$15,194**	**33.51**
Heating & Cooling	- Furnace (Gas or Oil)	243	$2,923	3.51	607	$5,459	8.57
	- Central Air Conditioner	114	$1,113	1.98	421	$3,067	6.71
	- Air-Source Heat Pump	82	$802	1.41	391	$2,831	6.23
	- Geothermal Heat Pump	10	$92	0.16	88	$626	1.40
	- Boiler (Gas or Oil)	13	$174	0.20	49	$495	0.74
	- Programmable Thermostat	174	$2,055	2.68	286	$2,649	4.25
	- Light commercial HVAC	58	$508	1.01	432	$2,875	6.88
	Subtotal	**694**	**$7,667**	**10.95**	**2,272**	**$18,003**	**34.78**
Lighting	- Fixtures	233	$2,273	4.04	1,209	$8,656	19.29
	- Exit Sign	29	$267	0.51	25	$181	0.40
	- Traffic Signal	47	$415	0.81	70	503	1.12
	Subtotal	**309**	**$2,955**	**5.36**	**1,304**	**$9,340**	**20.80**
Residential Appliances	- Dehumidifiers	7	$68	0.12	81	$777	1.76
	- Air Cleaners	3	$29	0.05	69	$519	1.17
	- Exhaust Fans	2	$23	0.04	24	$179	0.40
	- Ceiling Fans	3	$30	0.05	20	$148	0.33
	Subtotal	**15**	**$149**	**0.27**	**194**	**$1,382**	**3.09**
Commercial Appliances	- Water Coolers	19	$169	0.33	166	$1,078	2.65
	- Commercial Refrigeration	10	$87	0.17	71	$476	1.13
	- Hot Food Holding Cabinets	2	$22	0.04	49	$312	0.78
	- Fryers	1	$15	0.02	21	$157	0.30
	- Steamers	0	$2	0.00	9	$57	0.15
	- Vending Machines	3	$24	0.05	82	$518	1.31
	Subtotal	**36**	**$318**	**0.62**	**399**	**$2,598**	**6.32**
Other	- Utility Transformers	1	$5	0.01	1	$4	0.01
	- C&I Transformers	3	$28	0.05	9	$62	0.15
	- Residential Roofing	2	$13	0.03	30	$188	0.51
	- Commercial Roofing	87	$720	1.58	517	$3,259	8.51
	Subtotal	**93**	**$766**	**1.67**	**557**	**$3,512**	**9.17**
TOTAL		**4,795**	**$47,490**	**82.37**	**12,774**	**$89,646**	**202.57**

1) Columns may not total due to rounding.
2) Electricity is converted to primary energy using a conversion factor listed in Table 2
3) Disc = discounted, energy bills are calculated using yearly U.S. average energy prices (Table 2) and are discounted at 4%
4) Carbon emissions for electricity are listed in Table 2.

Over the period 2007 to 2015, US EPA's ENERGY STAR labeled products are projected to save 12.8 EJ of primary energy, $90 billion dollars in energy bills (4% discount rate), and avoid 203 Tg C eq. For reference, these carbon savings represent 3.3% of the projected US carbon emissions for the residential and commercial sectors over this period (US DOE 2007). The following product types account for 70% of future carbon avoided:

- Monitors: 33.5 Tg C (17% of total)
- Printers: 24.9 Tg C (12% of total)
- Computers: 21.8 Tg C (11% of total)
- Residential light fixtures: 19.3 Tg C (10% of total)
- TVs: 18.0 Tg C (9% of total)
- Furnaces: 8.6 Tg C (4% of total)
- Commercial roofing: 8.5 Tg C (4% of total)
- MFDs: 7.0 Tg C (3% of total)

Growth in savings due to US EPA's ENERGY STAR labeled products can be attributed to any of the following factors:

- addition of new product types to the ENERGY STAR brand;
- BAU technology trends and/or market changes that result in higher per unit savings for existing ENERGY STAR product types;
- increasing ENERGY STAR sales for existing ENERGY STAR product types;
- and/or future specification changes resulting in higher per unit savings for existing ENERGY STAR product types.

In terms of incremental carbon avoided in the forecast period (2007-2015) above the achieved carbon avoided to date (1993-2006), the following are the top four growing ENERGY STAR product types. These product types account for half of the absolute increase in carbon avoided during the forecast period:

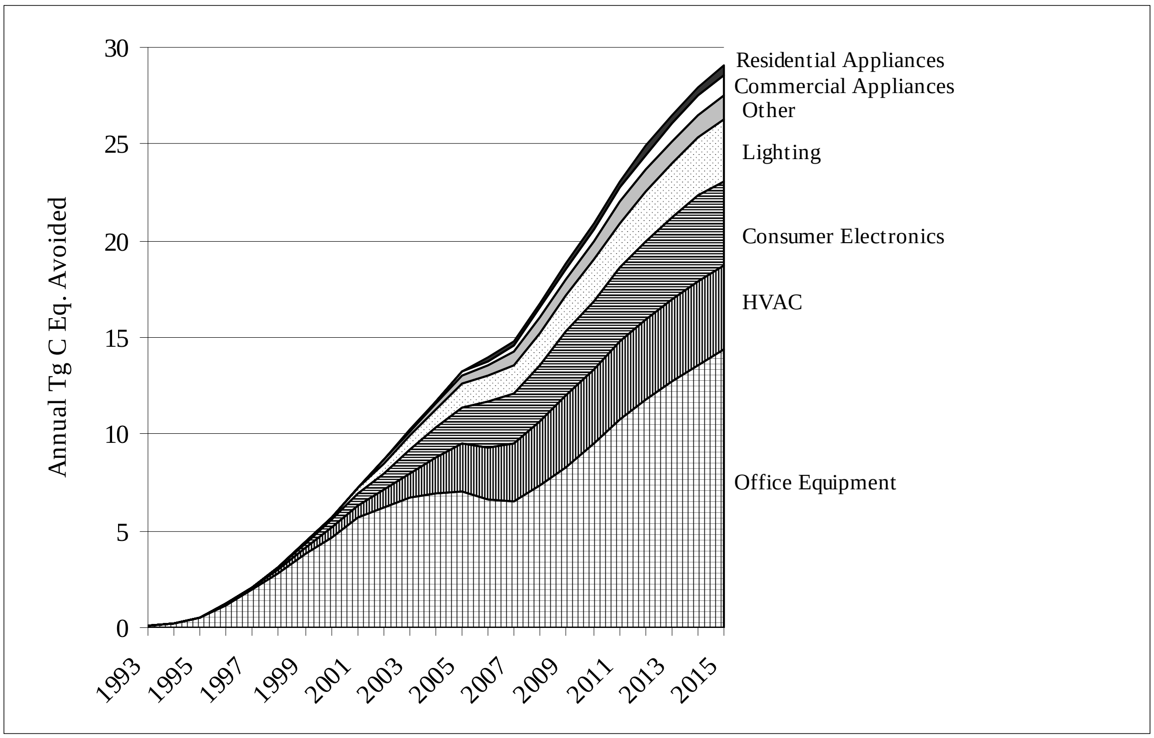
- Computers (delta 18.6 Tg C): growth in savings is primarily due to the addition of idle power energy requirements to the ENERGY STAR specification as well as tighter requirements for sleep and off mode. Idle mode savings are important because of low enabling rates (only 6% of desktop computers in the commercial sector power manage successfully even though 95% of office computers are equipped with power management capabilities). Office computers spend approximately 70% of the annual operating time in idle mode compared to only 4% of the annual operating time in sleep mode; residential computers spend 31% of the annual operating time in idle mode compared to only 6% of the annual operating time in sleep mode.
- Residential light fixtures (delta 15.3 Tg C): growth in savings is primarily due to the increase in ENERGY STAR unit sales. We project that the ENERGY STAR market share will increase from 4.6% in 2006 to 6.5% by 2015. Because the US sales volume is large, topping 200 million units each year, this program growth translates into an increase in ENERGY STAR unit sales from 11 million in 2006 to 18 million in 2015. The installed stock of ENERGY STAR units similarly climbs due to a 20-year average product lifetime.
- Printers (delta 14.3 Tg C): growth in savings is primarily due to the revision of the ENERGY STAR specification to reflect a TEC approach that targets all modes of operation in addition to just sleep and off mode. We estimate that printers are in active or job mode 20% of the annual operating time, in sleep mode 70% of the annual operating time, and in off mode 10% of the annual operating time.
- TVs (delta 14.1 Tg C): growth in savings is primarily due to the market shift away from CRT technology towards LCD technology. At the start of ENERGY STAR TVs in 1998, CRT technology was 100% of the market. By 2015, the market share for CRT TVs is projected to be only 2% and the market share for LCD TVs is over 60%. The UES for CRTs is only 46 kWh/yr whereas the UES for LCDs is 89 kWh/yr. The difference in UES is due to a higher standby power for LCDs in our BAU (11 W LCD vs. 6 W CRT).

Figure 2 shows the allocation of US EPA ENERGY STAR labeled product savings across the seven categories. Annual savings are estimated to increase from 0.1 Tg C eq. in 1993 to 13.9 Tg C eq. in 2006. We project annual savings will increase to 29.0 Tg C eq. in 2015[5]. The results show the critical importance of the office equipment product category to overall ENERGY STAR product savings. In 2006, ENERGY STAR

[5] For reference, 2006 ENERGY STAR labeled product carbon savings represents 2.2% of US carbon emissions for the residential and commercial sector. 2015 ENERGY STAR labeled product carbon savings represents 4.1% of carbon emissions for the residential and commercial sector (US DOE 2007).

office equipment avoided 6.6 Tg C or 48% of total annual carbon reductions for US EPA labeled products. We expect carbon reductions for ENERGY STAR office equipment to grow to 14.4 Tg C in 2015, representing 49% 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 2. Carbon Savings for US EPA ENERGY STAR labeled products (1993-2015)



Program strategies can include continuing to ensure relevance for the consumer market by recognizing and promoting only the most efficient subset of the office equipment market through tightened specifications (targeting the top quartile of energy performing models), continuing to find innovative ways to increase the energy performance of individual product types, continuing to aggressively target new product technologies and consumer usage/market trends that may offer additional savings opportunities (examples are digital networking and possible product convergence for televisions/monitors/personal computers and set-top boxes), and broadening the ENERGY STAR office equipment portfolio to include product types not historically targeted by the program (such as including wide-screen commercial displays/monitors, servers, and data centers).

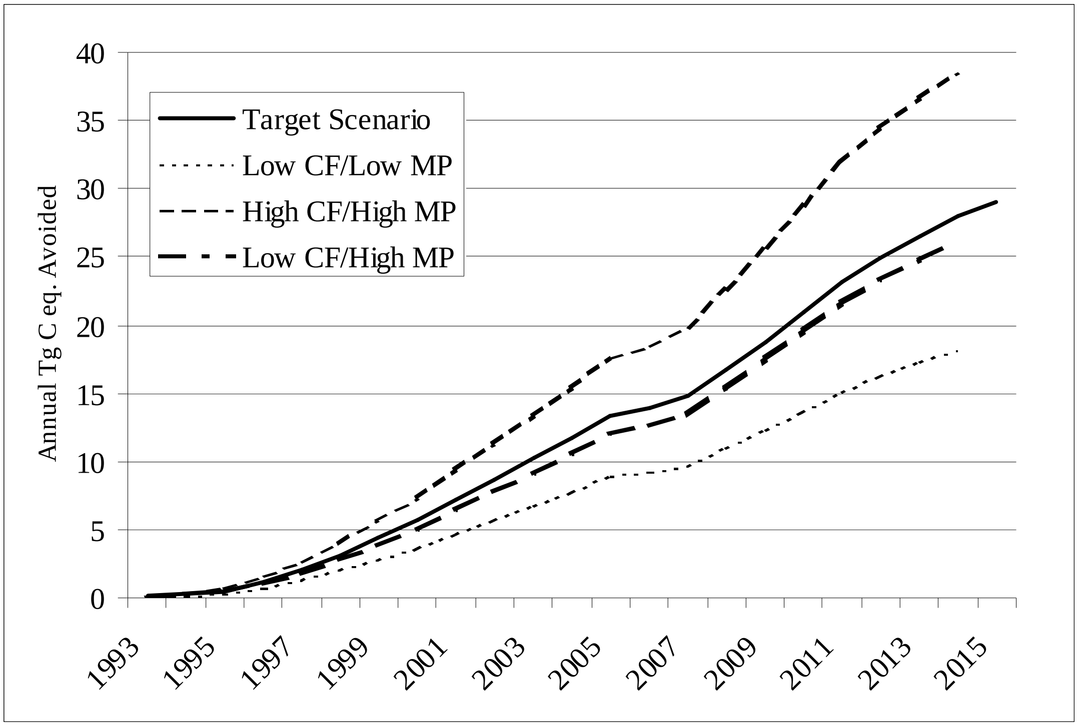
5.2 Sensitivity Analysis

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. We examined the sensitivity of the best-estimate carbon reductions under the following scenarios for the periods 1993 to 2006 and 2007 to 2015:

- the marginal carbon factor for electricity was reduced by 20%, ENERGY STAR sales were reduced by 20% (low CF/low MP)
- the marginal carbon factor for electricity was increased by 20%, ENERGY STAR sales were increased by 20% (high CF/high MP)
- the marginal carbon factor for electricity was reduced by 20% and ENERGY STAR sales were increased by 20% (low CF/high MP)

Figure 3 illustrates the results of this sensitivity analysis. These results bound the best estimate of carbon avoided between 54 Tg C and 107 Tg C for the period 1993-2006 (-34% and +31% from best estimate 82 Tg C) and 132 Tg C and 278 Tg C for the period 2007-2015 (-35% and +37% from best estimate 203 Tg C). The fluctuation in ENERGY STAR unit sales, fuel supply, fuel demand, and fuel mix are highly difficult to predict and model over the twenty-three year analysis period. However, even in a "worst case" scenario, the analysis shows substantial reductions in carbon achieved by US EPA ENERGY STAR labeled products.

Figure 3. Sensitivity Analysis of US EPA ENERGY STAR labeled products savings (1993-2015)



6. Limitations to the Analysis

The analysis is based on a bottom-up model for quantifying US 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 is essential, which can be a labor-intensive and expensive process. 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 generalize specific limitations to three main areas: forecasting, inputs, and model structure as shown in **Table 5**.

Table 5. Limitation 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 only 3. Power and usage data 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 US EPA and does not reconcile ENERGY STAR savings with supporting utility and procurement programs 3. Does not rigorously capture new/emerging technologies and its effect on baseline efficiency and ENERGY STAR savings 4. Model is reactive rather than active, meaning that the model is updated subsequent to a technology market changing

7. Conclusions

Since the program 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 US and international energy efficiency programs. This paper summarizes energy, carbon, and monetary impacts from US 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.

US EPA's ENERGY STAR labeled products has been successful in reducing carbon emissions through its voluntary labeling efforts. Through 2006, the program saved 4.8 EJ of primary energy and avoided 82 Tg C equivalent. The forecast shows that the program will save 12.8 EJ and avoid 203 Tg C equivalent over the period 2007-2015. The sensitivity analysis bounds the best estimate of carbon avoided between 54 Tg C and 107 Tg C (1993 to 2006) and between 132 Tg C and 278 Tg C (2007 to 2015).

Much of the program's success to date is attributable to ENERGY STAR office equipment products including monitors, computers, and imaging equipment. The analysis demonstrates the continued importance of this product category 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.

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