

# Savings estimates for the ENERGY STAR® voluntary labeling program

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## Abstract

ENERGY STAR® is a voluntary labeling program designed to identify and promote energy-efficient products. Operated jointly by the Environmental Protection Agency (EPA) and the US Department of Energy (DOE), ENERGY STAR labels exist for more than 20 products, spanning office equipment, residential heating and cooling equipment, new homes, commercial and residential lighting, home electronics, and major appliances. We present estimates of the energy, dollar and carbon savings already achieved by the program and provide savings forecasts for several market penetration scenarios for the period 2001–2010.

The target market penetration forecast represents our best estimate of future ENERGY STAR savings. It is based on realistic market penetration goals for each of the products. We also provide a forecast under the assumption of 100% market penetration; that is, we assume that all purchasers buy ENERGY STAR-compliant products instead of standard efficiency products throughout the analysis period. Finally, we assess the sensitivity of our target penetration case forecasts to greater or lesser marketing success by EPA and DOE, lower-than-expected future energy prices, and higher or lower rates of carbon emissions by electricity generators. Published by Elsevier Science Ltd.

## 1. Introduction

In the wake of the Kyoto summit on greenhouse gases, it has become even more important to assess the benefits of existing carbon reduction programs. This paper presents past and predicted savings for the ENERGY STAR® labeling program, operated jointly by the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE). Since 1993, the ENERGY STAR label has been used to promote high-efficiency office equipment, heating and cooling equipment, appliances and lighting.

Our forecast of future savings extends through 2010. We include both a 100% market penetration case and a target market penetration case using the market share goals used by EPA and DOE. The paper also considers the impact on energy, energy bill and carbon savings if the programs fall short or exceed their market penetration goals, if energy prices fall, and for two alternative paths of carbon emissions rates for electricity generation.

## 2. The ENERGY STAR® labeling program

ENERGY STAR is a voluntary product labeling program operated jointly by EPA and DOE. Those agencies enter into agreements with manufacturers that allow the manufacturers to promote products meeting certain energy efficiency and performance criteria through the use of the ENERGY STAR label. EPA and DOE have focused their efforts in areas where efficiency improvements can be achieved while offering the same or improved level of service. However, the ENERGY STAR label does not constitute an endorsement of the product by EPA or DOE.

The EPA launched the ENERGY STAR program in 1993 with computers, monitors and printers. The goal was to promote energy-saving features already common in laptop computers for use in desktop devices. These labeled products soon dominated the market, largely due to President Clinton issuing Executive Order 12845 requiring that microcomputers, monitors and printers purchased by federal agencies be ENERGY STAR-compliant. The sheer size of the federal market pushed manufacturers to participate in the program. Now we estimate that 95% of monitors, 85% of computers and 99% of printers sold are ENERGY STAR-compliant.

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In 1995, fax machines, copiers, residential heating and air conditioning equipment, thermostats, new homes and exit signs were added to the labeling program. In 1996, DOE agreed to work jointly with EPA to promote energy-efficient products using the ENERGY STAR logo. Because energy efficiency is equal parts environmental protection and energy policy, the DOE/EPA partnership was an important step in developing and expanding ENERGY STAR. In 1996, DOE introduced ENERGY STAR labels for refrigerators, room air conditioners, clothes washers and dishwashers. Scanners, multi-function devices and residential lighting fixtures were added to EPA's labeled products in 1997, followed by TVs and VCRs in 1998. DOE introduced an ENERGY STAR label for windows in 1998 and for screw-based compact fluorescent lamps in 1999.<sup>1</sup>

EPA and DOE continue to research products and industries in search of new program opportunities. Factors evaluated include the potential for improvements in unit energy savings, the size of the stock, turnover rates and the structure of the industry.

### 3. Methodology

We begin by calculating the stock of ENERGY STAR units in place in each year of the analysis. To do this, we apply market penetrations to total annual product shipments to obtain annual shipments of ENERGY STAR devices. In order to correctly measure the effects of the ENERGY STAR program we explicitly account for the baseline penetration of high-efficiency units which would have met the ENERGY STAR requirement even if the program did not exist. Only shipments of ENERGY STAR units over and above this baseline (i.e. those that can be attributed to the program) are counted toward ENERGY STAR program savings.

Some products, particularly office equipment, do not accrue savings unless the ENERGY STAR features are enabled. In the past, manufacturers sometimes shipped devices with ENERGY STAR features disabled. Manufacturers are now required to ship units enabled, so no user action is required to achieve energy savings. However, users may disable features for various reasons, such as slow recovery times from low-power modes or incompatibility with computing networks. Research suggests that only half of all ENERGY STAR computers have the power-saving features enabled (Koomey *et al.*, 1995). For products where this is a problem, we estimate an enabling rate in each year, which we apply to the number of ENERGY STAR units shipped to get the number of new ENERGY STAR units that accrue savings.

Using annual installations of energy-saving units, we calculate the number of ENERGY STAR units in place in each year by applying a simple retirement model. Devices are assumed to remain in place and accrue savings for a period equal to the average lifetime of the product (given in Table 3 below), then are retired.

Annual unit energy savings are assumed to be constant as long as the ENERGY STAR requirements are not tightened during the forecast period. This assumption may overstate savings somewhat, since many products have achieved significant energy efficiency improvements even in the absence of efficiency programs. The way we account for baseline penetration of high-efficiency (ENERGY STAR-qualifying) units captures a large portion of the reference case efficiency improvement. However, potential improvements in the average efficiency of non-qualifying units is not taken into account. Energy savings estimates are national averages derived from monitored data (where possible) or engineering estimates.

Unit energy savings are multiplied by the number of enabled ENERGY STAR units in place in each year to get aggregate annual energy savings. Aggregate energy bills are estimated using year-by-year energy prices from US DOE (1996a, b, 1997b, 1998b, 1999), shown in Table 1. 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. Carbon emissions factors for electricity (Cadmus, 1998) are also shown in Table 1.

#### 3.1. Forecasting issues

##### 3.1.1. Office equipment

ENERGY STAR-labeled office equipment includes computers, monitors, fax machines, printers, copiers, scanners and multi-function devices (MFDs). The program focuses on reducing the power consumed by these devices when not in active use. ENERGY STAR devices automatically enter a low-power mode and/or turn themselves off after a period of inactivity. To qualify for the ENERGY STAR label, devices must incorporate low-power and/or auto-off modes, and must meet power consumption limits in those modes. In some cases, default power-saving settings are specified, such as the length of the idle period necessary to trigger a lower-power mode or a maximum recovery time from low-power modes.

For our analysis, we used operating patterns derived from equipment audits at various locations (Piette *et al.*, 1995; Nordman *et al.*, 1998). These sources provided both the time spent in each operating mode (e.g. active, standby, suspend and off), and the percent of ENERGY STAR devices that were actually enabled. Baseline unit energy consumptions were calculated by multiplying the time spent in each power mode by the power consumption in each mode, then summing over all power modes. The unit energy consumption for ENERGY STAR products

<sup>1</sup> Windows and screw-based compact fluorescent lamps have not yet been added to our forecasts.

Table 1  
Best estimate energy prices and carbon emissions factors by year<sup>a</sup>

Year	Commercial electricity price 1998\$/kWh	Residential electricity price 1998\$/kWh	Gas price 1998\$/GJ	Oil price 1998\$/GJ	Price source	Carbon emissions factor for electricity (kg C/kWh)	Carbon source
1993	0.087	0.093	6.93	6.28	US DOE (1996a) <sup>b</sup>	0.203	Cadmus (1998)
1994	0.086	0.092	6.48	6.58	US DOE (1996b) <sup>b</sup>	0.203	Cadmus (1998)
1995	0.080	0.089	6.03	6.34	US DOE (1997b) <sup>b</sup>	0.203	Cadmus (1998)
1996	0.079	0.087	6.12	7.00	US DOE (1998b) <sup>b</sup>	0.203	Cadmus (1998)
1997	0.076	0.084	6.47	6.77	US DOE (1999)	0.203	Cadmus (1998)
1998	0.074	0.080	6.26	5.80	US DOE (1999)	0.203	Cadmus (1998)
1999	0.073	0.080	6.26	5.99	<sup>c</sup>	0.203	Cadmus (1998)
2000	0.072	0.079	6.26	6.19	<sup>c</sup>	0.203	Cadmus (1998)
2005	0.066	0.075	6.27	7.16	US DOE (1999)	0.148	Cadmus (1998)
2010	0.064	0.074	6.23	7.34	US DOE (1999)	0.135	Cadmus (1998)
2015	0.063	0.073	6.09	7.41	US DOE (1999)	0.135	<sup>c</sup>
2020	0.062	0.073	6.03	7.47	US DOE (1999)	0.135	<sup>c</sup>
> 2020	0.062	0.073	6.03	7.47	<sup>c</sup>		<sup>c</sup>

<sup>a</sup>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. For the low-energy price sensitivity case, gas, oil and electricity prices were reduced by 10% for 2001–2010. For the high and low carbon emissions cases, the carbon coefficients for electricity were multiplied by 1.2 and 0.8, respectively, for the period 2001–2010.

<sup>b</sup>All prices have been converted to 1998 dollars using implicit GDP deflators from the US Department of Commerce (2000).

<sup>c</sup>Where there were gaps in the forecast, missing values were filled in using linear interpolation. The carbon coefficient for electricity is assumed to remain constant after 2010. Energy prices are assumed to remain constant after 2020.

Table 2  
Enabling rates (%) for ENERGY STAR office equipment<sup>a</sup>

Product	1993	1994	1995	1996	1997	2000	2005	2010
Copiers	NA	NA	90	90	90	90	90	90
Facsimile	NA	NA	90	90	90	90	90	90
Printers	80	90	90	90	90	90	90	90
Scanners	NA	NA	NA	NA	90	90	90	90
Multi-function devices	NA	NA	NA	NA	100	100	100	100
Monitors	10	15	15	60	80	80	80	80
PCs	10	15	15	50	50	50	50	50

<sup>a</sup>Enabling rates represent the percent of ENERGY STAR-compliant devices assumed to be correctly configured for power management and successfully saving energy.

was calculated essentially the same way, although some of these products have additional power modes. ENERGY STAR products also have different usage patterns than standard products (because of features like auto-off) and lower power levels in certain operating modes. Office equipment shipment data were obtained from Dataquest (1997a, b), Infotrends Research Group (1998) and Lyra Research (1998). The unit energy savings were applied to forecasts of enabled, ENERGY STAR-compliant devices to obtain aggregate savings.

As noted above, taking account of enabling rates was particularly important for office equipment. A significant number of ENERGY STAR devices, particularly computers, fail to save energy because either their power management features are not enabled or external factors (such as computer network connections) keep the device from entering low-power modes. Although success rates have

improved significantly since the program began, we are unlikely to see 100% success rates in the foreseeable future given variations in computing environments, networking issues and the rate of technological change. Table 2 shows the office equipment enabling rates assumed in the analysis.

Because of different usage patterns, computers and monitors were modeled separately for homes and offices. We assumed that 64% of shipments for these products are used in offices.

### 3.1.2. Residential heating and cooling (HVAC)

The HVAC program covers air-source heat pumps, geothermal heat pumps, central air conditioners, gas and oil furnaces, gas-fired heat pumps, gas and oil boilers, and programmable thermostats. For heating and cooling equipment, ENERGY STAR eligibility is based solely on

efficiency, measured by standard test procedures such as AFUE or SEER.<sup>2</sup> Programmable thermostats qualify for the ENERGY STAR label because they automate what people often fail to do manually: set back their thermostats at night or when they are out of the house. Several issues arose in analyzing heating and cooling equipment, including multiple fuel types, technology substitution and program interactions.

The shipment forecasts for ENERGY STAR HVAC equipment (excluding thermostats) is based on EPA's sales training activities. EPA provided estimates of the expected increase in annual sales for each salesperson trained, which was used to forecast total increased sales due to the trainings. By focusing on EPA HVAC promotional activities rather than attempting to count ENERGY STAR device sales directly, we avoided the need to account for ENERGY STAR HVAC installed due to other programs, particularly the ENERGY STAR Homes program.

Energy bill and carbon savings both depend on the type of fuel used. In addition to their primary fuels, gas and oil furnaces and gas-fired heat pumps consume electricity to operate fans. Programmable thermostats save energy according to the type of HVAC installed in the home. For these products, we segmented the analysis by fuel type, then added the component savings together.

Technology substitution is an issue for new technologies that are not yet in widespread use, such as geothermal and gas-fired heat pumps. As these technologies increase in market share, they will displace shipments of established products. In our forecast, we assumed that geothermal heat pumps would displace air-source heat pumps and gas-fired heat pumps would displace gas furnaces and central air conditioning. The impact of gas-fired heat pumps in our target market penetration case is insignificant, since the technology has proven to be unsuccessful in the market and shipments are assumed to be zero from 1999 onward. In the 100% market penetration scenario, however, we do assume some replacement of gas furnaces and central air conditioners with gas-fired heat pumps.

Because programmable thermostats reduce the operating hours of heating and cooling equipment, they must be analyzed in conjunction with HVAC equipment to avoid double-counting savings from thermostats and efficient equipment. Because we calculate thermostat savings as a percentage of total heating and cooling energy, thermostat savings should be lower if ENERGY STAR-compliant HVAC equipment is in place. Conversely, if there is a programmable thermostat in place, replacing old equipment with an ENERGY STAR model will save less than if the thermostat was a standard one. For simplicity, we assumed that HVAC equipment is chosen first and therefore ENERGY STAR HVAC receives its full measure of

savings. Programmable thermostat savings were calculated from a forecast of HVAC energy use that took into account the increasing market penetration of ENERGY STAR HVAC (we assumed the choice of a programmable thermostat was independent of the choice of ENERGY STAR HVAC).

### 3.1.3. Consumer electronics

For TVs, VCRs and audio equipment, ENERGY STAR focuses on reducing devices' standby power. Savings are assumed to accrue in both active and standby mode, since functions like remote control and memory are powered whether the device is on or off. The power savings are only a few watts per unit, but the number of units is large. There are about 190 million TVs and almost 140 million VCRs in the United States (Sanchez *et al.*, 1998). We estimate that some 54 million audio devices are sold each year, including amplifiers, receivers, tuners, CD players, cassette players, equalizers, radios, mini-systems, rack systems, DVDs and laserdiscs. Car audio and portable audio products are not included in this total, since they are not covered under the program.

The biggest difficulty in forecasting TV and VCR power consumption was obtaining unit power consumption data. When EPA began to develop the program, the most recent data available on television energy use were over 10 years old, and virtually no data were available for VCRs or audio equipment. New metered data collected by researchers at LBNL and the Florida Solar Energy Center provided the basis for developing the product label. Once the TV/VCR agreement was in place these values were updated using shipment-weighted power consumption values provided by industry representatives (Isaacs, 1998). Our TV and VCR shipment forecasts were developed using historic shipment data from *Appliance* (1995).

### 3.1.4. Residential lighting

The ENERGY STAR residential lighting fixtures program promotes energy-efficient lighting fixtures. These include fixtures designed for compact fluorescent lamps (CFLs), electronically ballasted tube fluorescent fixtures, and outdoor fixtures that incorporate motion sensors and photocells. DOE's new screw-based CFL program was not treated in this analysis.

We analyze the residential lighting fixture market in three segments: torchieres, other indoor fixtures, and outdoor fixtures. Torchieres were split out because the market is dominated by high-wattage halogen fixtures – 300–500 W. ENERGY STAR CFL replacements for these fixtures have proven to be a great success, and market penetrations for these products are higher than for other ENERGY STAR fixtures. Torchierie energy savings are calculated using data from Calwell (1999) and Calwell and Granda (1999). Shipment data for other indoor fixtures and outdoor fixtures were from the US Department of Commerce (1997).

<sup>2</sup> AFUE is average fuel utilization efficiency and SEER is seasonal energy efficiency ratio.

For indoor fixtures, we assumed that the target market was fixtures operated more than 3 h/day. Higher-cost CFLs are often not cost-effective in low-use fixtures. Although these fixtures used more than 3 h/day represent less than 20% of the fixture stock, they use more than 60% of household lighting energy (Wenzel *et al.*, 1997). By focusing only on high-use fixtures we increase the expected per-unit savings but limit the maximum penetration that can be achieved. Unit energy consumption for high-use indoor fixtures was taken from the Baseline Residential Lighting Energy Use Study (described in Vorsatz *et al.*, 1997). In reality, some high-efficiency fixtures will probably end up in low-use applications, but we assumed this would be in addition to the high-use applications and did not account for this effect. For the 100% penetration scenario, we assumed that 100% of high-use fixtures were replaced (about 17% of all fixtures). Low-use fixtures were not replaced in the 100% scenario.

Our analysis of outdoor fixtures focused on motion sensor- and photocell-equipped fixtures. Baseline energy consumption was again taken from the Baseline Residential Lighting Energy Use Study. As with indoor fixtures, we focused on high-use fixtures, although for different reasons. Outdoor fixtures, especially around entryways, are often left on all night for security. Motion sensor fixtures are particularly suited for this type of application. A motion sensor was assumed to reduce usage to 1 h/day.

### 3.1.5. Commercial lighting

Although exit signs may seem like a small niche in the commercial lighting market, they were an ideal target for an ENERGY STAR program. Exit signs must be lit 24 h a day. Most signs use incandescent lamps for illumination, which consume about 40 watts. ENERGY STAR exit signs must consume less than five watts. Because of the importance of visibility during emergencies, the program also requires that products meet visibility and luminance requirements.

Calculating energy savings for exit signs was fairly straightforward. However, there is some uncertainty associated with the size of the stock, shipments and lifetime. The lifetime for some light sources (LED and electroluminescent) are reported to be 20 years or more, but because efficacy may degrade over time we use a more conservative 10 year lifetime.

### 3.1.6. Appliances

After HVAC and water heating, large appliances, including refrigerators, clothes washers, dishwashers, and room air conditioners (RACs), constitute the largest energy end-uses in a typical home. Like some of the HVAC products, these appliances are already subject to federal minimum efficiency standards. The ENERGY STAR program is intended to expand the market for products that significantly exceed the minimum standard. The

requirements are 20% more efficient than standards for refrigerators, 13% for dishwashers and 50% for clothes washers. The ENERGY STAR specification for RACs is 15% more efficient than standards through September 2000, when new efficiency standards go into effect. After October 1, 2000, the ENERGY STAR specification will be 10% more efficient than the new standard. New standards go into effect for refrigerators July 1, 2001, and DOE has proposed an ENERGY STAR specification of 10% more efficient than the new standard. DOE has also proposed tightening the dishwasher requirement to 25% more efficient than the current standard beginning January 1, 2001. Our forecasts assume the proposed refrigerator and dishwasher specifications are approved.<sup>3</sup>

To obtain energy use for these ENERGY STAR devices, we first calculated unit energy consumption for units just meeting the federal minimum efficiency standards. The average energy consumptions for refrigerators and RACs (under both existing and new efficiency standards) were weighted according to the distribution of products by product class and capacity (Wenzel *et al.*, 1997 US DOE, 1995b, 1997a). In the case of dishwashers and clothes washers a prototypical model was used to calculate energy consumption. Since these ENERGY STAR criteria are specified in terms of percent efficiency improvement over standards, the appropriate percentages were then applied to obtain ENERGY STAR energy consumption.

A large share of the energy savings for clothes washers and dishwashers is due to the use of household hot water, which may be heated using gas, oil, LPG or electricity. (Because oil and LPG water heaters represent only a small fraction of water heaters, they were treated together with gas water heaters for this analysis.) The remaining energy savings may be attributed to the motor, controls, or, in the case of dishwashers, internal water heating, all of which use electricity. We therefore analyzed clothes washer and dishwasher energy savings in three parts: machine energy, which accrued to all devices, electric water heating energy, which accrued to devices installed in electric water heating homes, and gas water heating energy, which accrued to devices installed in gas water heating homes (oil and LPG water heating homes were also included here). The shares of water heating by fuel type were taken from Wenzel *et al.* (1997). Unit energy consumption and savings for clothes washers and dishwashers included machine energy and weighted-average water heating energy for all fuels, expressed as primary energy.

### 3.1.7. Homes

The ENERGY STAR homes program works with builders to encourage the construction of energy-efficient homes.

<sup>3</sup> DOE will announce its revised specifications for refrigerators and dishwashers by June 1, 2000.

Table 3  
Annual and lifetime savings per unit for ENERGY STAR® devices sold in 2000<sup>a</sup>

Equipment type	% Annual energy savings <sup>b</sup> (%)	Annual unit primary energy savings <sup>c</sup> (GJ/yr)	Annual bill savings due to ENERGY STAR <sup>d</sup> (1998\$/unit)	Product lifetime <sup>d</sup> (years)	Lifetime energy savings <sup>e</sup> (GJ/unit)	Lifetime energy bill savings, undiscounted <sup>f</sup> (1998\$/unit)
Office equipment						
Office computer and monitor	56	3.1	\$20	4	12	\$79
Home computer and monitor <sup>g</sup>	50	0.90	\$6.4	4	3.6	\$25
Fax	55	1.9	\$12	4	7.4	\$47
Copier	33	3.2	\$21	6	19	\$120
Multifunction devices	43	6.9	\$45	6	41	\$260
Scanner	69	2.8	\$18	4	11	\$71
Printer	62	2.2	\$14	5	11	\$69
Consumer electronics						
TV	19	0.38	\$2.7	11	4.2	\$29
VCR	27	0.18	\$1.3	11	1.9	\$13
TV/VCR	19	0.35	\$2.5	11	3.9	\$26
Audio equipment	43	0.18	\$1.3	7	1.2	\$8.6
Residential heating and cooling						
Furnace (gas or oil)	15	13	\$86	18	240	\$1,500
Central air conditioner	19	6.7	\$47	14	93	\$630
Air-source heat pump	13	18	\$130	12	220	\$1,500
Geothermal heat pump	30	58	\$410	15	870	\$5,900
Gas-fired heat pump	34	45	\$320	15	680	\$4,600
Boiler (gas or oil)	7	7.4	\$46	20	150	\$910
Programmable thermostat	20	22	\$150	15	330	\$2,200
Residential lighting						
Fixture	73	2.1	\$15	20	42	\$280
Commercial lighting						
Exit sign	88	3.4	\$22	10	34	\$210
New home <sup>h</sup>	24	36	\$240	30	1100	\$7000
Appliances						
Room air conditioner <sup>i</sup>	10	0.70	\$4.9	13	9.1	\$98
Dishwasher	13	0.60	\$4.2	13	7.8	\$52
Refrigerator <sup>j</sup>	16	1.2	\$8.7	19	23	\$160
Clothes Washer <sup>j</sup>	47	2.6	\$21	14	37	\$220

<sup>a</sup>Files used for this analysis are available at <http://enduse.lbl.gov/Projects/ESIImpacts.html>.

<sup>b</sup>Annual savings are relative to standard new unit, with the following qualifications: Geothermal heat pump is compared to air-source heat pump and electric water heater. Gas-fired heat pump is compared to gas furnace and central air conditioner. Residential lighting fixtures are compared to a standard incandescent fixture. Copier and multifunction device savings are for models meeting the Tier 2 requirements, effective in 1998 for copiers and in 2000 for MFDs. Exit sign savings are compared to standard incandescent fixtures. For HVAC and New Homes, the standard energy bills are derived from 1990 RECS consumption data.

<sup>c</sup>Electricity is converted to primary energy using a conversion factor of 11,079 kJ/kWh (US DOE, 1995a). For clothes washers and dishwashers this saving is the sum for machine and water heating energy for all fuel types.

<sup>d</sup>Yearly US average energy prices are from US DOE (1996a, b, 1997b, 1998b, 1999), shown in Table 1. Lifetime energy bill savings are calculated using the stream of future energy prices.

<sup>e</sup>Lifetimes are the average lifetime for each product. Computer, monitor, copier, printer and fax lifetimes are from Koomey *et al.*, 1995 (the short lifetimes for computers reflects rapid obsolescence for those products); scanner lifetimes are assumed to be the same as those of fax machines; TV and VCR lifetimes are from *Appliance* (1996); gas furnace, central air conditioner, air-source heat pump and boiler lifetimes are from Lewis and Clarke (1990); geothermal and gas-fired heat pumps are LBNL estimates; thermostat lifetime is the weighted average of HVAC lifetimes; exit sign life is from National Lighting Product Information (1994); new home life is based on a typical 30 year mortgage; appliance lifetimes are from Wenzel *et al.* (1997).

<sup>f</sup>Lifetime energy savings may not equal the product of annual energy savings and product lifetime due to rounding.

<sup>g</sup>Usage assumptions for home computers and monitors differ from office computers and monitors, resulting in different unit savings.

<sup>h</sup>Savings for ENERGY STAR homes are assumed to be 30% for heating and cooling and 10% for water cooling. A full breakdown of savings by fuel types is available at <http://enduse.lbl.gov/Projects/ESIImpacts.html>.

<sup>i</sup>The ENERGY STAR room air conditioner specification will be tightened from October 1, 2000. The savings presented in the table are for units sold after that date.

<sup>j</sup>The savings for refrigerators and clothes washers given here are lower than the percent savings over efficiency standards specified by the ENERGY STAR program (20 and 50%, respectively) because here we are comparing to standard new units, which are more efficient than the minimum standard. Refrigerator savings are from US DOE (1995b). Clothes washer savings are from US DOE (1998a).

The goal is to construct homes that consume 30% less energy for heating, cooling, and hot water than equivalent homes meeting the national Model Energy Code. To meet the ENERGY STAR requirements, a home must receive a home energy rating system (HERS) rating of at least 86 or the equivalent. To meet program guidelines, homes typically have a variety of upgrades, such as increased insulation, reduced infiltration, high-performance windows, high-efficiency heating and cooling equipment, and reduced losses in ducts.

Average new single-family home energy consumption for heating, cooling and hot water were estimated by census division from the 1990 RECS data set. These estimates were aggregated using 1993 housing permits as the weighting factor. Single-family housing completions (the equivalent of shipments for the other products) were assumed to be a constant one million units per year over the forecast period.

Other government-funded programs promote whole-house efficiency, including Building America and PATH. Homes built under these programs may also qualify as an ENERGY STAR home. Such homes were included in the reference case, and were not counted toward ENERGY STAR Homes savings.

## 4. Results

Table 3 shows annual unit energy and energy bill savings, average product lifetime, and lifetime energy and energy bill savings for each product. These estimates form the basis of the calculation of savings to date and the forecasts of future savings. ENERGY STAR geothermal heat pumps have the highest absolute per unit savings, followed by gas-fired heat pumps. ENERGY STAR homes also have high per-unit savings. As noted above, homes are expected to incorporate several energy saving measures in order to qualify for ENERGY STAR. In terms of percentage savings, however, exit sign savings are largest at 88%. Other products with at least 50% savings are computers, fax machines, scanners, printers, residential lighting fixtures and clothes washers.

Table 4 presents our estimates of achieved ENERGY STAR program savings through the end of 1999 (cumulative) and our forecast of 2000 savings. Because the biggest determinant of achieved savings is how long the program has been in place, we have included the start year for each program. Office equipment is the largest source of savings to date. The ENERGY STAR Program has saved 760 petajoules of primary energy since the first product labels were introduced in 1993, for cumulative energy bill savings of \$5.2 billion. The addition of new products combined with increased market penetration for existing products is increasing annual savings at a rapid rate. With the addition of year 2000 savings, estimated at 370

petajoules and \$2.5 billion, total cumulative savings will increase by almost 50%.

We provide savings forecasts for two cases: a target market penetration case, using EPA's and DOE's market penetration goals for ENERGY STAR devices, and a 100% market penetration case, assuming that all shipments are ENERGY STAR-compliant (but not necessarily enabled, see below) from 2001 onward. We also consider the effect of deviations from target market penetrations, falling energy prices, and two alternative paths for carbon emissions factors for electricity. Each scenario is based on the same set of underlying assumptions about unit energy consumption and savings, presented in Table 3.

### 4.1. Target market penetration case

This case represents the best estimate of the long-term aggregate savings achievable by ENERGY STAR programs given the market penetration goals and unit energy savings estimates of the individual programs. The target market penetration case uses unit savings estimates and year-by-year penetration targets with the best available estimates of inputs such as energy prices and carbon emission factors. The target market penetrations are based, in part, on the price premium for ENERGY STAR units. Because ENERGY STAR computers and monitors are no more expensive than non-ENERGY STAR devices, they are expected to represent a large share of the market (85–95%) by 2010. In contrast, high-efficiency heating and cooling equipment is significantly more expensive than standard equipment. The total target market penetrations for HVAC equipment (including baseline high-efficiency shipments) range from 34% for oil furnaces to 66% for oil boilers. Table 5 shows the reference case market penetration of high-efficiency units and the total penetration of ENERGY STAR units in the target market penetration case in 1995, 2000, 2005 and 2010.

Table 6 shows the cumulative savings from 2001 to 2010 under target market penetrations. Computers (CPUs and monitors) result in the biggest savings primarily due to the large market share of ENERGY STAR devices and steep growth in the number of units in place. Residential lighting fixtures and exit signs also result in significant savings. Although residential fixtures have only a moderate penetration the number of units shipped each year is large, resulting in a large number of ENERGY STAR units in place, each with a high unit savings. ENERGY STAR exit signs have high unit savings and a large market share. Although geothermal and gas-fired heat pumps have high per unit savings, their aggregate savings are quite low due to low projected market penetrations. We expect geothermal heat pumps to gain market share slowly because of their higher cost. Gas-fired heat pumps are no longer being sold.

Table 4  
Cumulative savings through 1999 and Year 2000 annual savings<sup>a</sup>

Program	Equipment type	Start year	Cumulative savings through 1999			Annual savings in 2000		
			Primary savings <sup>b</sup> (petajoules)	Energy bill savings, undiscounted <sup>c</sup> (millions of 1998\$)	Carbon avoided <sup>d</sup> (MtC)	Primary savings <sup>b</sup> (petajoules)	Energy bill savings undiscounted <sup>c</sup> (millions of 1998\$)	Carbon avoided <sup>d</sup> (MtC)
Office equipment	Computers and monitors	1993	360	\$2,500	6.6	160	\$1,000	2.8
	Faxes	1995	21	\$150	0.39	5.8	\$38	0.11
	Copiers	1995	26	\$180	0.48	15	\$95	0.27
	Multifunction devices	1997	0.41	\$2.7	0.0075	0.52	\$3.3	0.0094
	Scanners	1997	27	\$180	0.50	26	\$170	0.48
	Printers	1993	150	\$1,000	2.8	41	\$260	0.74
	Subtotal		590	\$4,000	11	240	\$1,600	4.5
Consumer electronics	TVs	1998	6.3	\$45	0.12	9.1	\$65	0.17
	VCRs	1998	3.0	\$22	0.055	3.7	\$26	0.068
	TV/VCRs	1998	0.50	\$3.6	0.0092	0.67	\$4.8	0.012
	Audio equipment	1999	1.9	\$14	0.035	2.9	\$20	0.052
	Subtotal		12	\$85	0.22	16	\$120	0.30
Residential heating & cooling	Furnaces (gas or oil)	1995	1.4	\$8.8	0.020	2.5	\$16	0.036
	Central air conditioners	1995	0.83	\$6.0	0.015	1.5	\$11	0.028
	Air-source heat pumps	1995	0.54	\$3.9	0.010	0.96	\$6.8	0.018
	Geothermal heat pumps	1995	0.14	\$1.0	0.0026	0.27	\$1.9	0.0050
	Gas-fired heat pumps	1995	0.00036	\$0.0025	0.0000064	0.00018	\$0.0013	0.0000032
	Boilers (gas or oil)	1995	0.069	\$0.42	0.0011	0.12	\$0.77	0.0020
	Programmable thermostats	1995	39	\$260	0.62	19	\$130	0.31
	Subtotal		42	\$280	0.67	25	\$160	0.40
New homes	New homes	1995	0.80	\$5.4	0.013	1.4	\$9.3	0.023
Res lighting	Fixtures	1997	14	\$99	0.250	24	\$170	0.43
Com lighting	Exit signs	1995	41	\$270	0.75	48	\$310	0.88
Appliances	Room air conditioners	1996	7.3	\$54	0.13	2.4	\$17	0.044
	Dishwashers	1996	5.3	\$38	0.091	2.1	\$14	0.036
	Refrigerators	1996	21	\$150	0.38	5.0	\$35	0.091
	Clothes washers	1996	31	\$220	0.55	4.4	\$30	0.076
	Subtotal		64	\$470	1.1	14	\$97	0.25
Total			760	\$5,200	14	370	\$2,500	6.7

<sup>a</sup>Columns may not total due to rounding. Files used for this analysis are available at <http://enduse.lbl.gov/Projects/ESIImpacts.html>.

<sup>b</sup>Electricity is converted to primary energy using a conversion factor of 11,079 kJ/kWh (US DOE, 1995a).

<sup>c</sup>Energy bills are calculated using yearly U.S. average energy prices from US DOE (1996a, b), US DOE (1997b), US DOE (1998b), US DOE (1999). See Table 1.

<sup>d</sup>Carbon emissions for electricity are from Cadmus (1998). See Table 1.

#### 4.2. 100% Market penetration

Our 100% market penetration scenario shows the savings that could be achieved if everyone bought ENERGY STAR equipment instead of standard equipment from 2001 to 2010. Because geothermal heat pumps

and gas-fired heat pumps are new technologies without a defined baseline market share, these technologies are assumed to seize a share of the markets for more traditional technologies. Geothermal heat pumps are assumed to displace half of non-ENERGY STAR air-source heat pumps, while gas-fired heat pumps displace 10% of



Table 5  
Reference penetrations (%) and target market penetrations (%) for ENERGY STAR® products<sup>a</sup>

Product	Start year	1995 Ref case <sup>b</sup>	Target	2000 Ref case <sup>b</sup>	Target	2005 Ref case <sup>b</sup>	Target	2010 Ref case <sup>b</sup>	Target
Office equipment									
Monitors	1993	0.0	92.7	0.0	95.0	0.0	95.0	0.0	95.0
Computers	1993	0.0	73.7	0.0	85.0	0.0	85.0	0.0	85.0
Facsimiles	1995	0.0	30.0	0.0	95.0	0.0	95.0	0.0	95.0
Copiers	1995	0.0	23.8	0.0	52.3	0.0	56.9	0.0	61.5
Multifunction devices	1997	NA	NA	0.0	30.0	0.0	30.0	0.0	30.0
Scanners	1997	NA	NA	0.0	30.0	0.0	30.0	0.0	30.0
Printers	1993	0.0	94.4	0.0	99.0	0.0	99.0	0.0	99.0
Consumer electronics									
TVs	1998	NA	NA	2.4	40.0	2.4	90.0	2.4	90.0
VCRs	1998	NA	NA	5.0	55.0	5.0	65.0	5.0	65.0
TV-VCRs	1998	NA	NA	0.0	30.0	0.0	50.0	0.0	50.0
Audio <sup>c</sup>	1999	NA	NA	39.5	54.4	10.6	32.6	10.0	38.0
HVAC									
Gas furnace	1995	21.9	21.9	24.0	27.5	24.0	39.4	24.0	57.2
Oil furnace	1995	1.0	1.0	1.0	4.5	1.0	16.4	1.0	34.2
Central air conditioner	1995	19.2	19.2	22.9	26.4	22.9	38.3	22.9	56.1
Air source heat pump	1995	19.2	19.2	29.0	32.5	29.0	44.4	29.0	62.2
Geothermal heat pump <sup>d</sup>	1995	100	100	100	103	100	115	100	133
Gas fired heat pump <sup>d</sup>	1995	100	100	100	100	100	100	100	100
Gas boiler	1995	1.0	1.0	1.0	4.5	1.0	16.4	1.0	34.2
Oil boiler	1995	33.0	33.0	33.0	36.5	33.0	48.4	33.0	66.2
Programmable thermostats	1995	20.0	20.0	25.8	35.5	34.8	41.4	43.8	46.0
New homes									
Homes	1995	0.0	0.0	0.8	3.0	9.4	37.5	22.8	91.4
Residential lighting									
Fixtures	1997	NA	NA	1.0	2.8	1.0	5.8	1.0	10.8
Commercial lighting									
Exit signs	1995	10.0	10.0	10.0	73.0	10.0	73.0	10.0	73.0
Appliances									
RACs <sup>c</sup>	1996	NA	NA	0.7	8.4	0.0	3.2	0.0	5.0
Dishwashers <sup>c</sup>	1996	NA	NA	2.0	30.0	0.0	14.4	0.0	20.0
Refrigerators <sup>c</sup>	1996	NA	NA	10.0	21.0	0.0	4.1	0.0	8.0
Clothes washers	1996	NA	NA	0.5	9.5	0.5	12.0	0.5	12.5

<sup>a</sup>Penetrations represent percent of new product sales in each year.

<sup>b</sup>Reference case is the baseline market penetration in the absence of the ENERGY STAR Program. Target penetration includes the reference case penetration.

<sup>c</sup>In some cases the reference case penetration is lower in later years, due to an anticipated tightening the ENERGY STAR requirement. Additional changes in the reference case penetration for audio equipment are due to expected changes in the mix of audio products on the market.

<sup>d</sup>All geothermal and gas-fired heat pumps qualify for the ENERGY STAR label, so baseline penetrations are 100% for these technologies. Additional sales due to the ENERGY STAR program are indicated by increasing the penetration beyond 100%. The additional sales of geothermal heat pumps replace air-source heat pumps, while sales of gas-fired heat pumps displace gas furnaces and central air conditioners, as described in the text.

the gas furnace market. The 100% penetration forecasts for air-source heat pumps, gas furnaces and central air conditioners take into account this loss of market to the new technologies. As noted above, the “100% penetration” forecast for residential lighting fixtures applies to only high-use fixtures, about 17% of all fixtures sold.

The 100% market penetration scenario should not be interpreted as a technical potential, because although we assume that all units sold are ENERGY STAR, we do not assume that all units sold are properly enabled. Studies have noted less than 100% enabling rates of ENERGY STAR features in office equipment, particularly copiers, computers and monitors (see Table 2).

The cumulative savings for the 100% market penetration scenario are also shown in Table 6. Together the programs could save 23 exajoules between 2001 and 2010, for a total energy bill savings of \$120 billion savings (present value, discounted at 4%). These totals are more than twice the savings in the target market penetration case. The largest savings in this case are due to residential lighting, even though we assumed that 100% penetration only applied to high-use fixtures.

#### 4.3. Sensitivity analysis

The market penetration achieved is one of many factors that influences the savings that will be realized. As

Table 6  
Cumulative savings 2001–2010<sup>a</sup>

Program	Equipment type	Target market penetrations <sup>b</sup>				100% Market penetration case			
		Primary energy savings <sup>c</sup> (PJ)	Energy bill savings <sup>d,e</sup> (millions of 1998 dollars)		Carbon avoided <sup>f</sup> (MtC)	Primary energy savings <sup>c</sup> (PJ)	Energy bill savings <sup>d,e</sup> (millions of 1998 dollars)		Carbon avoided <sup>f</sup> (MtC)
			Undiscounted	Discounted			Undiscounted	Discounted	
Office equipment	Computers and monitors	2,200	\$14,000	\$11,000	31	2,400	\$15,000	\$12,000	33
	Faxes	13	\$81	\$74	0.21	13	\$83	\$75	0.21
	Copiers	210	\$1,300	\$1,000	2.9	230	\$1,400	\$1,100	3.2
	Multifunction devices	38	\$220	\$170	0.50	120	\$710	\$540	1.6
	Scanners	510	\$3,000	\$2,400	7.0	1,600	\$9,300	\$7,300	21
	Printers	590	\$3,800	\$3,000	8.1	590	\$3,800	\$3,000	8.1
	Subtotal	3,600	\$22,000	\$18,000	49	4,900	\$30,000	\$24,000	67
Consumer electronics	TVs	630	\$4,300	\$3,300	8.3	820	\$5,500	\$4,300	11
	VCRs	140	\$930	\$730	1.8	200	\$1,300	\$1,000	2.6
	TV/VCRs	49	\$330	\$250	0.64	95	\$640	\$480	1.2
	Audio equipment	160	\$1,100	\$830	2.1	540	\$3,700	\$2,800	7.1
	Subtotal	980	\$6,600	\$5,100	13	1,700	\$11,000	\$8,600	22
Residential heating and cooling	Furnaces (gas or oil)	350	\$2,200	\$1,700	4.8	1,700	\$11,000	\$8,100	23
	Central air conditioners	220	\$1,500	\$1,100	2.9	1,100	\$7,200	\$5,500	14
	Air-source heat pumps	130	\$850	\$640	1.6	320	\$2,100	\$1,600	4.2
	Geothermal heat pumps	62	\$420	\$310	0.80	990	\$6,700	\$5,100	13
	Gas-fired heat pumps <sup>g</sup>	0.0018	\$0.012	\$0.0098	0.000025	570	\$3,800	\$2,900	7.6
	Boilers (gas or oil)	17	\$120	\$86	0.28	100	\$660	\$500	1.5
	Programmable thermostats	350	\$2,300	\$1,800	5.0	1,500	\$9,600	\$7,400	21
	Subtotal	1,100	\$7,400	\$5,600	15	6,200	\$41,000	\$31,000	84
New homes	New homes	460	\$3,000	\$2,200	6.1	1,500	\$9,700	\$7,500	20
	Fixtures	1,600	\$11,000	\$8,200	21	4,500	\$30,000	\$23,000	60
	Com lighting	1,500	\$9,200	\$7,200	21	2,000	\$12,000	\$9,400	27
	Appliances	60	\$410	\$330	0.83	210	\$1,400	\$1,100	2.8
	Dishwashers	85	\$560	\$440	1.1	320	\$2,100	\$1,600	4.3
	Refrigerators	160	\$1,100	\$880	2.2	390	\$2,600	\$2,100	5.3
	Clothes washers	340	\$2,300	\$1,800	4.6	1,400	\$9,200	\$7,000	18
	Subtotal	660	\$4,400	\$3,500	9.0	2,400	\$16,000	\$12,000	32
Total		10,000	\$63,000	\$49,000	130	23,000	\$150,000	\$120,000	310

<sup>a</sup>Columns may not total due to rounding. Files used for this analysis are available at <http://enduse.lbl.gov/Projects/ESIImpacts.html>.

<sup>b</sup>Target market penetrations represent EPA's and DOE's best estimates of the percent of equipment shipped that is ENERGY STAR. These estimates are based on past market penetrations, manufacturer commitments, and EPA's and DOE's long-term goals. 100% market penetration scenario assumes all equipment shipped from 1998 onward is ENERGY STAR-compliant.

<sup>c</sup>Electricity is converted to primary energy using a conversion factor of 11,079 kJ/kWh (US DOE, 1995a).

<sup>d</sup>Cumulative bill savings do not take into account increased investment costs. Cumulative bill savings are discounted using a 4% real discount rate.

<sup>e</sup>Yearly US average energy prices are from US DOE (1996a, b, 1997b, 1998b, 1999). See Table 1.

<sup>f</sup>Carbon emissions for electricity are from Cadmus (1998). See Table 1.

<sup>g</sup>All savings for gas-fired heat pumps in the target market penetration case are for units shipped before 1999.

Table 7  
Cumulative energy, dollar and carbon savings under different sets of assumptions

	Market penetration		High	100%
	Low	Target		
Cumulative primary energy savings 1993–2010 (exajoules)	9.5	11	12	24
Cumulative carbon savings 1993–2010 (million metric tonnes Carbon)				
Low carbon emissions factor	110	130	140	280
Baseline carbon emissions factor	130	160	170	330
High carbon emissions factor	150	180	200	390
Cumulative dollar savings 1993–2010 (millions of 1998\$, present value)				
Baseline energy price scenario	\$50,000	\$58,000	\$64,000	\$120,000
Low energy price scenario	\$42,000	\$49,000	\$54,000	\$100,000

noted above, simply getting the product to market does not guarantee savings. User behavior may differ from what we have modeled, which could affect savings either positively or negatively. Changes in energy prices will affect dollar savings and changes in carbon emissions from electrical generation will affect carbon savings. The energy prices and electric carbon factors used in our target market penetration and 100% market penetration scenarios are shown in Table 1. The decline in the electric carbon factor reflects a shift toward cleaner electric generation technologies.

In light of these uncertainties, we analyzed the sensitivity of the energy, dollar and carbon savings in our target penetration case to the following changes of assumptions:

1. Energy prices were reduced by 10% beginning in 2001.
2. The carbon emissions factors for electricity were increased by 20% beginning in 2001.
3. The carbon emissions factors for electricity were decreased by 20% beginning in 2001.
4. Market penetrations were reduced by 20% (penetrations were multiplied by 0.8) beginning in 2001.
5. Market penetrations were increased by 20%, up to 100% (the scenario penetration was the lesser of 100% or 1.2 times the target market penetration) beginning in 2001.

Our target penetration case and 100% market penetration forecasts already incorporate a decline in electricity and gas prices (based on EIA forecasts, US DOE, 1999). The 10% reduction would be on top of that decrease. We do not model high/low enabling rates as a separate case, since this has the same effect as a change in market penetrations: it decreases the number of activated units in place.

Changing the market penetration affects aggregate energy savings and therefore bill savings and carbon savings as well. A decrease in energy prices, however, affects only energy bill savings.<sup>4</sup> The electricity carbon

factor affects only carbon savings, not energy or bill savings. Table 7 shows total ENERGY STAR program savings under different combinations of these assumptions.

Fig. 1 compares annual carbon savings under the 100% market share scenario, the target market penetration scenario, the low carbon factor/low market share case and the high carbon factor/high market share case. Although the most pessimistic case represents a large reduction over the target penetration case, it nonetheless achieves significant carbon savings.

## 5. Limitations of the analysis

Our estimates of unit energy consumptions for office equipment and consumer electronics are calculated from underlying usage patterns and power consumption estimates. We face limitations on two fronts: First, there have been limited data collected for many of these products. As more information has become available, we have updated our forecasts, and we will continue to do so in the future. Such data can change our estimates significantly. In the case of high-speed copiers, recent research into copier energy use significantly reduced our estimates of baseline unit energy consumption and therefore reduced estimated savings. Second, there is great diversity in power consumption within each product category, and we lack the data to create a precise shipment-weighted average energy consumption.

We did not account for the possibility of improvements in the efficiency of non-ENERGY STAR units over the analysis period, although we do include increases in the number of ENERGY STAR units not attributable to the program. As an example, our analysis takes into consideration increases in the number of horizontal axis (ENERGY STAR-qualifying) clothes washers that might have occurred in the absence of the program, but it does not take into account efficiency improvements that might be occurring in non-qualifying vertical-axis washers. Since we calculate savings relative to non-ENERGY STAR units (vertical axis washers, in this case), we may be

<sup>4</sup> Although falling energy prices might also have the effect of reducing market penetrations (by reducing the benefits of efficiency investments), we do not model this indirect effect.

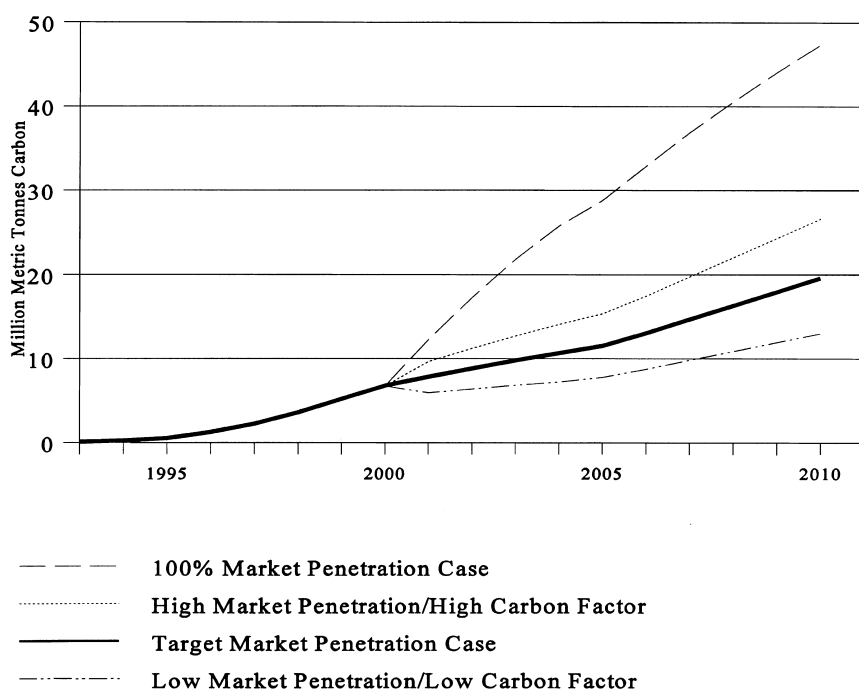


Fig. 1. Annual carbon savings.

crediting the program with savings that should be attributed to a general trend toward increasing energy efficiency. Accounting for this effect would certainly reduce estimated program savings, but was beyond the scope of this study.

Our analysis focuses exclusively on the ENERGY STAR Program and does not attempt to rigorously reconcile the projected effects of the program with the existence of other overlapping efficiency programs. The reference case market penetration of ENERGY STAR Homes, although it is intended to include homes built due to other government-funded whole-house programs, was not based on an explicit examination of such programs.

Procurement programs and utility rebate programs now use the ENERGY STAR label to identify qualifying products, reducing the costs of designing and operating these programs while helping to boost the market share of ENERGY STAR products. This analysis does not attempt to account for these interactions, and therefore the savings presented here include savings which might legitimately be claimed by other energy conservation programs. Sorting through the universe of efficiency programs to assess all potential interactions was beyond the scope of this analysis. Care should be taken, therefore, in combining these savings forecasts with those of other programs.

Although we account for existing and finalized future efficiency standards, we chose not to speculate about possible future standards and how they might affect the savings due to the various ENERGY STAR labels in the future. Such standards would probably trigger a tightening in the ENERGY STAR requirement, which would reduce

the number of products qualifying for a label. A stringent enough standard could even eliminate the need for an ENERGY STAR label. The products affected by standards include central air conditioners, heat pumps, room air conditioners, furnaces, boilers, refrigerators, clothes washers and dishwashers.

Technological developments already on the horizon will likely force us to revise our forecast in the not-too-distant future. This issue is particularly striking in consumer electronics. The advent of high-definition television will undoubtedly affect TV power consumption, and recordable DVDs could supplant VCRs in the near future. We believe that EPA and DOE will try to leverage their existing partnerships with manufacturers to extend the ENERGY STAR label to new technologies. The face of office equipment is also changing as the popular media heralds the advent of the “post-PC” era (Galarza and Clark, 2000). Because of the uncertainties associated with this type of technological change, we made no attempt to model these changes.

Our analysis extends only to 2010, and we made no attempt to account for savings that might accrue after that time.

## 6. Conclusions

ENERGY STAR has already proven successful in its established programs, having achieved energy savings of 740 petajoules and prevented 13 million metric tonnes of carbon from being emitted. Based on our analysis here, the continuation of those programs and the addition of

new programs in appliances and home electronics have the potential to greatly reduce carbon emissions over the next 10 years. Our sensitivity analysis bounds our expectation of cumulative energy bill savings estimates between \$40 billion and \$57 billion through 2010 (present value). However, as EPA and DOE continue to work to improve savings through consumer education, partnerships with manufacturers, new product labels, and tightening requirements for existing products, the ENERGY STAR program may be able to achieve even higher savings in the future. If ENERGY STAR-labeled products could achieve 100% market penetration, \$150 billion could be saved from estimated energy bills over the next 10 years (present value).

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## References

- Appliance, 1995. Statistical Review. April, pp. 45–48.
- Appliance, 1996. A Portrait of the U.S. Appliance industry 1996. September, pp. 85–91.
- Cadmus (The Cadmus Group, Inc and Energy Systems Consulting, Inc.), 1998. Regional electricity emissions factors. Prepared for the US Environmental Protection Agency, May.
- Calwell, C., 1999. Customers turn out for torchiere trade-in. *Home Energy* 16 (2), 32–35.
- Calwell, C., Granda, C., 1999. Halogen torchiere market transformation: a look at progress to date and future strategies. Natural Resources Defense Council, September.
- Dataquest, 1997a. Personal computers 1997 U.S. forecast update. PCIS-WW-MS-9707, November.
- Dataquest, 1997b. U.S. copier 1996 market share and forecast. COPY-NA-MS-9701, April.
- Galarza, P., Clark, B., 2000. Winners and losers: investing in a post-PC era. *Money* 29 (5), 74–84.
- Infotrends Research Group, Inc., 1998. Scanner market forecast and outlook. Prepared for ICF Incorporated on behalf of US EPA ENERGY STAR Office Equipment Programs, March.
- Isaacs, D., (EIA/CEMA), 1998. Personal communication, discussion with Stephan Sylvan of EPA, September 3, 1997.
- Koomey, J., Cramer, M., Piette, M.A., Eto, J., 1995. Efficiency improvements in U.S. office equipment: expected policy impacts and uncertainties. Lawrence Berkeley Laboratory, LBL-37383, December.
- Lewis, J.E., Clarke, A., 1990. Replacement market for selected commercial energy service equipment (Topical Report: Phase 1B–Commercial). Gas Research Institute, GRI-89/0204.02, June.
- Lyra Research, Inc., 1998. Single-function fax machine forecast. Prepared exclusively for Environmental Protection Agency, March.
- National Lighting Product Information, 1994. Specifier Reports: Exit Signs. Vol. 2, Number 2. Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, March.
- Nordman, B., Piette, M.A., Pon, B., Kinney, K., 1998. It's midnight...is your copier on?: energy star copier performance. Lawrence Berkeley National Laboratory, LBNL-41332, February.
- Piette, M.A., Cramer, M., Eto, J., Koomey, J., 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 LBL-36752, January.
- Sanchez, M., Koomey, J., Moezzi, M., Meier, A., Huber, W., 1998. Miscellaneous electricity use in the U.S. residential sector. Lawrence Berkeley National Laboratory, LBNL-40295, April.
- US Department of Commerce, 1997. Electric lighting fixtures–1996. Current Industrial Reports MA36L(96)-1. Bureau of the Census, September.
- US Department of Commerce, 2000. Implicit GDP deflator. Bureau of Economic Analysis, <http://www.bea.doc.gov/bea/dn1.htm>. March 6.
- US DOE, US Department of Energy, 1995a. Monthly energy review. DOE/EIA-0035(95/05), Energy Information Administration, May.
- US DOE, US Department of Energy, 1995b. Technical support document: energy efficiency standards for consumer products: refrigerators, refrigerator/freezers and freezers. US Department of Energy, Energy Efficiency and Renewable Energy, Office of Codes and Standards, Washington, DC., DOE/EE-0064, July.
- US DOE, US Department of Energy, 1996a. Annual energy outlook 1996 with projections to 2015. DOE/EIA-0383(96), Energy Information Administration, January.
- US DOE, US Department of Energy, 1996b. Annual energy outlook 1997 with projections to 2015. DOE/EIA-0383(97), Energy Information Administration, December.
- US DOE, US Department of Energy, 1997a. Technical support document for energy conservation standards for room air conditioners. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Codes and Standards. [http://www.eren.doe.gov/buildings/codes\\_standards/reports/index.htm](http://www.eren.doe.gov/buildings/codes_standards/reports/index.htm). September.
- US DOE, US Department of Energy, 1997b. Annual energy outlook 1998 with projections to 2020. DOE/EIA-0383(98), Energy Information Administration, December.
- US DOE, US Department of Energy, 1998a. Preliminary technical support document: energy efficiency standards for consumer products: clothes washers (TSD). US Department of Energy, Energy Efficiency and Renewable Energy, Office of Codes and Standards, Washington, DC, October.
- US DOE, US Department of Energy, 1998b. Annual energy outlook 1999 with projections to 2020. DOE/EIA-0383(99), Energy Information Administration, December.
- US DOE, US Department of Energy, 1999. Annual energy outlook 2000 with projections to 2020. DOE/EIA-0383(2000), Energy Information Administration, December.
- Vorsatz, D., Shown, L., Koomey, J., Moezzi, M., Denver, A., Atkinson, B., 1997. Lighting market sourcebook for the U.S. Lawrence Berkeley National Laboratory, LBNL-39102, December.
- Wenzel, T., Koomey, J., Rosenquist, G., Sanchez, M., Hanford, J., 1997. Energy data sourcebook for the U.S. residential sector. Lawrence Berkeley National Laboratory, LBNL-40297, September.