Supporting Information

Dietz et al. 10.1073/pnas.0908738106

SI Text

This supplementary document defines the 33 specific actions that constitute the 17 action types identified in Table 1 and explains how we estimated PER and RAER for each action. The next section, *Current Penetration Estimates*, explains our estimates of current penetration of each action—the proportion of the relevant population currently engaging in it. The third section, *Potential Emissions Reductions*, explains our estimates of PER for each action—the emissions reduction that would be achieved nationally if penetration increased to 100%. The main report explains our estimates of behavioral plasticity—the proportion of those not yet adopting the action who could be induced to do so in the near term with the most effective combination of nonregulatory interventions. The fourth section, *Reasonably Achievable Emissions Reduction*, explains how we estimated RAER, which corrects PER for the limits of behavioral plasticity and for the nonadditivity of actions (e.g., weatherizing a house reduces the impact of thermostat setbacks; use of LRR tires reduces the impact of more efficient driving behaviors). The final section, *Baseline Energy Use and Emissions*, documents our sources for energy consumption and greenhouse gas emissions for the U.S. household sector.

Our analysis considers the following specific actions.

W: Weatherization and Upgrades of Home Heating and Cooling Systems. Weatherization (3 actions): (*i*) weather-strip to seal drafts; (*ii*) adequately insulate attic space; (*iii*) replace single-paned windows with triple-pane windows with low-emissivity coatings.

HVAC equipment (2 actions): (*i*) replace older furnace; (*ii*) replace central AC unit with Energy Star model.

E: Equipment Upgrades. Low-flow showerheads: replace high-volume showerheads with low-flow ones that have flow rates of no more than 2.0 gallons per minute (gpm). Current federal standards require 2.5 gpm or less.

Efficient water heater (two actions): (*i*) replace non–Energy Star water heater with Energy Star model; (*ii*) install an insulating blanket on an electric water heater.

Appliances (3 actions): (*i*) replace large-screen plasma television with rear-projection or liquid crystal display (LCD) unit; (*ii*) replace non–Energy Star refrigerator with Energy Star model; (*iii*) replace non–Energy Star clothes washer with Energy Star model.

Low rolling resistance (LRR) tires: replace high rolling resistance tires on car with LRR ones.

Fuel efficient vehicle: replace 20.8-mpg vehicle (current fleet average) with 30.7-mpg model.

M: Maintenance of Equipment. Change HVAC air filters: replace home ventilation filters for heating and central AC every month in season.

Tune up AC: annual professional inspection and tune-up of central AC.

Routine auto maintenance (4 actions): (*i*) regular oil changes; (*ii*) change oxygen sensor at recommended intervals; (*iii*) remove excess weight from vehicle; (*iv*) maintain recommended tire pressure.

A: Adjustments of Equipment. Laundry temperature: reduce hot water consumption by washing clothes on warm/cold cycle.

Water heater temperature: set back water heater to recommended 120°F.

D: Daily Use Behaviors. Reduce standby electricity: reduce standby use of electricity by appliances and electronics by 90%.

Thermostat setbacks (6 actions): (*i*) set back heating thermostat in winter from 72°F to 65°F during day when no one is home, (*ii*) to 68°F during day when someone is home, and (*iii*) to 65°F at night; (*iv*) set "up" AC thermostat in summer from 73°F to 80°F during day when no one is home, (*v*) to 78°F during day when someone is home, and (*vi*) to 78°F at night. These settings can be maintained manually or by use of a programmable thermostat. Note that the settings above were based on published suggested targets (1).

Line drying: air-dry clothes during spring and fall (5 months per year) instead of using dryer.

Driving behavior (3 actions): (*i*) reduce acceleration rate and unnecessary braking; (*ii*) maintain 55 mph speed for highway driving; (*iii*) reduce idling time.

Carpooling and trip-chaining (2 actions): (*i*) carpool by adding 1 passenger for every single-occupant commuting trip; (*ii*) combine errands to reduce errand mileage by half.

Current Penetration Estimates

We define current penetration as the percentage of the relevant population that had, as of the end of 2008, taken an emissions-reduction action. Where possible, we took estimates from national databases. Where the estimates are several years old or where we believe penetrations are changing rapidly, we have updated these data to 2008 by extrapolating from previous data where appropriate. For actions for which empirical data were lacking, we made current penetration estimates on the basis of informal, expert sources. In general, we attempted to be conservative—to err on the side of greater current penetration so that our estimates of PERs would not be overly optimistic.

W: Weatherization and Upgrades of Home Heating and Cooling Systems. ***Sealing drafts.*** We estimate current penetration in homes using space heating at 63% and in homes using central AC at 70%. Table HC2.5 of the 2005 Residential Energy Consumption Survey (RECS 2005) (2) reports that 109.1 million homes use space heating equipment and that 62.9 million (58%) of these homes report that the "home is never too drafty during the winter." We raised the resulting figure by 5%, conservatively presuming an increased prevalence of this emissions-reduction action between 2005 and 2008, resulting in a current penetration estimate of 63%.

Table HC2.7 of RECS 2005 (2) reports that 65.9 million homes use central AC and that 42.6 million (65%) report that the "home is 'never' too drafty during the summer." We raised the resulting figure by 5%, conservatively presuming an increased prevalence of this emissions-reduction action between 2005 and 2008, resulting in a current penetration estimate of 70%.

Insulate attic space. We estimate current penetration for homes using space heating at 44% and in homes using central AC at 50%.

Table HC2.5 of RECS 2005 (2) reports that 109.1 million homes use space heating equipment, and that 42.8 million (39%) report that the home's "adequacy of insulation" was "well insulated." We raised the resulting figure by 5%, allowing for increased prevalence of this emissions-reduction action between 2005 and 2008.

Table HC2.7 of RECS 2005 (2) reports that 65.9 million homes use central cooling equipment and that 29.5 million (45%) report that the home's "adequacy of insulation" was "well-insulated."

We raised the resulting figure by 5% to allow for increased prevalence of this emissions-reduction action between 2005 and 2008.

Replace single-pane windows. We estimate current penetration at 60% for homes using space heating and 63% for homes using central AC. Table HC2.5 of RECS 2005 (2) reports that 109.1 million homes have space heating equipment, and that 59.9 million (55%) report that the "type of glass in windows" was "double-pane glass" or "triple-pane glass." We raised the resulting figure by 5% to account for increased prevalence of this emissions-reduction action between 2005 and 2008.

Table HC2.7 of RECS 2005 (2) reports that 65.9 million homes use central AC and that 38.1 million (58%) report that the "type of glass in windows" was "double-pane glass" or "triple-pane glass." We raised the resulting figure by 5% to account for increased prevalence of this emissions-reduction action between 2005 and 2008.

HVAC Equipment. *Replace older furnace.* We estimate current penetration of high-efficiency furnaces at 38%. On the basis of the manufacturers' stated lifetimes of 17 years, we assume that no household would trade in a furnace less than 14 years old. We extrapolated from data concerning the age of heating equipment and heating fuel type from Table HC2.4 of RECS 2005 (2) and data on market penetration of Energy Star furnaces (a program begun in 1995 for furnaces). For market penetration, explicit federal government data were available only for furnaces sold in 2004–2007, so we extrapolated for units sold in 1994–2003 and in 2008 (3–6).

More specifically, the 38% figure is the average of estimated market penetration of Energy Star furnaces [percentage of total gas, oil, or propane/liquefied petroleum gases (LPG)] weighted by the number of furnaces in use for each model year (which we extrapolated from the data in Table HC2.4. We used "less than 2 years old" to refer to furnaces purchased in 2007–2008, and so on). We estimated market penetration, for furnaces sold between 2004 and 2007, according to the relevant "Energy Star Unit Shipment and Market Penetration Report Calendar Year Summary"; for 2008 units, we assumed the same figure as for 2007 units; for 2000–2003 units, we assumed 40% market penetration (extrapolated from 42%, the average penetration of 2004–2007 units); and we conservatively assumed 35% market penetration for 1995–1999 units. Our analysis does not include electric furnaces because the models currently being sold already exceed Energy Star minimum standards.

Replace older central AC. We estimate current penetration at 18%. Similarly as with furnaces, we assume that no household would trade in a central AC unit less than 14 years old and extrapolate from data concerning the age of central AC equipment in Table HC2.6 of RECS 2005 (2) and data on market penetration of Energy Star central AC units (as with furnaces, this program started for central AC equipment in 1995). For market penetration, explicit federal government data were only available for units sold in 2005–2007, so we extrapolated for units sold in 1994–2004 and in 2008 (4–6).

More specifically, the 18% figure is the average of estimated market penetration of Energy Star central AC units, weighted by the number of units in use for each model year (the latter extrapolated from the data in RECS 2005. We used "less than 2 years old" to refer to AC units purchased in 2007–2008, and so on). We estimated market penetration for AC units sold between 2005 and 2007 according to the relevant "Energy Star Unit Shipment and Market Penetration Report Calendar Year Summary"; for 2008 units, we assumed the same figure as for 2007 units; for 2004 units, we assumed 18% market penetration (extrapolated from 19.3% average of penetration of 2005–2007 units); for 2000–2003 units, we assumed 17% market penetration (extrapolated from 18%, the average penetration we estimated for 2004 units); and we conservatively assumed 15% market penetration for 1995–1999 units.

E: Equipment Upgrades. ***Low-flow showerheads.*** A recent review of potential efficiency gains from showerheads reported that 24% of showerheads do not satisfy the federal standard of 2.5 gpm and estimated the average flow in these noncompliant showerheads at 3.25 gpm (7). Of the 76% of showerheads that comply with this standard, an unknown fraction have substantially lower flow than mandated by current regulations (e.g., 2.0 gpm), but there has been significant resistance to the current standard, so we assume a 10% penetration of 2.0-gpm showerheads as a conservative estimate. Thus, current penetration for 2.0-gpm showerheads is taken as 10%, but calculations of emissions reductions require us to consider 2 tiers of current equipment. For details, see the discussion of PER in *Potential Emissions Reductions*, below.

Efficient water heater. We estimate that 10% of households with gas water heaters and 35% with electric water heaters have high-efficiency units meeting January 2009 Energy Star specifications.

High-efficiency gas water heaters have been available for sale only since 2006 and first appeared in popular media (e.g., *Consumer Reports*) in 2008. Because we could find no research data on their current penetration, we made a subjective estimate of 10% that we consider high when product replacement rates are taken into account.

For electric heaters, we combine the distribution of ages of existing units reported in Table HC2.8 of RECS 2005 (2) and federal regulations, which required a minimum energy factor 0.9 starting in 2004 (8), to arrive at an estimate that 35% of households had an electric heater with an energy factor 0.9 or greater. We could not find data on the prevalence of insulating blankets on electric water heaters, but in our judgment 60% penetration is a reasonably conservative estimate.

Appliances. *Replace plasma TV.* We estimate current penetration at 77%: industry reports of high-definition TV (HDTV) sales estimated roughly that at the end of 2007, 40 million households had at least 1 HDTV, with sales of roughly 20 million per year, of which 23% are plasma sets (9). We add 20 million sets to account for sales during 2008 and assume the same ratio of 23% plasma and 77% nonplasma sets.

Energy Star refrigerator. We estimate current penetration at 27%. Tables HC2.9 and HC2.10 of RECS 2005 report that 111.1 million households have a refrigerator and that in 23.9 million of these households the "most-used refrigerator" is an Energy Star unit (2), yielding a penetration rate of 21.6%. We raised the resulting figure by 5% to account for increased penetration of Energy Star between 2005 and 2008, and rounded up to 27%. We did not make estimates of potential savings from upgrading less-used refrigerators.

Energy Star clothes washer. We estimate current penetration at 29%. Tables HC2.9 and HC2.10 of RECS 2005 report that 91.8 million households have a washer and that 21.7 million of these are Energy Star (2), yielding a penetration rate of 23.7%. We raised the resulting figure by 5% to account for increased penetration of Energy Star between 2005 and 2008, and rounded up to 29%.

LRR tires. We estimate current penetration at 10%. The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy reports that new vehicles are routinely equipped with LRR tires to help meet Corporate Average Fuel Economy (CAFE) requirements (10), but because replacement tires are not labeled for rolling resistance, consumers cannot choose them easily. Because we could find no research data on the prevalence of LRR tires in the replacement tire market, we based the estimate loosely on both the estimate in "Slower acceleration, unnecessary braking" (see below) and on our judgment.

Fuel-efficient vehicle. We estimate current penetration at 5%. The 30.7 mpg current penetration criterion figure (average adjusted composite fuel economy) is based on the 26 most fuel-efficient vehicles in the Fuel Economy Leaders section of the U.S. Department of Energy/Environmental Protection Agency (DOE/EPA)'s 2009 *Fuel Economy Guide* (11). The set excludes passenger vans, cargo vans, midsize station wagons, and standard pick-up trucks but includes vehicles in all other categories, including 2-seater, minicompact, subcompact, compact, midsize, and large autos, as well as small station wagons, minivans, sport utility vehicles, and small pick-up trucks.

We estimate current penetration of fuel-efficient vehicles by considering the fraction of light-duty vehicles on the road today with adjusted composite (55/45) mileage greater than 30 mpg (sales data are reported in 5-mpg bins). Distribution of fuel economy, based on sales figures for each model year since 1975, is reported by the EPA (12). We weight the penetration of efficient vehicles in each model year by the fraction of cars and trucks of different ages, as reported by the Office of Energy Efficiency and Renewable Energy (13), to calculate the distribution of fuel economy for all light-duty vehicles on the road. This calculation gives a current penetration of 3.9%.

We checked this estimate using a different strategy. Sales-weighted average DOE/EPA composite mpg for autos and for light-trucks remained nearly constant from 1985 through 2007 (14). In addition, the percentage of auto vs. light-truck sales remained relatively constant for the calendar years for which we could obtain manufacturers' sales data, 2000–2007 (15, 16). We combined manufacturers' sales data for each auto and light-truck make and model for a recent calendar year (2003) (17) with corresponding DOE/EPA data on fuel efficiency (composite mpg 55/45) for each model (18). In 2003, only 9 makes/models had mpg ratings above our criterion of 30.7 mpg. These accounted for approximately 3.6% of total auto/light-truck sales. Average annual mileage per vehicle decreases with vehicle age (19), but this trend may be counteracted by decreasing fuel efficiency with vehicle age. If these 2 tendencies cancel each other out, we get a current penetration estimate of ≈4%, as with the other method of calculation. Our 5% estimate for current penetration thus seems realistic and, if anything, slightly conservative.

M: Maintenance of Equipment. *Change HVAC air filters.* We estimate current penetration at 50%. According to Tables HC2.4 and HC2.6 of RECS 2005 there are ≈109 million households with central heating (warm air, steam or hot water, or electric heat pump) and 66 million with central AC (2). Because the data tables do not identify housing units with both central heating and central AC, and because any unit with both usually has a stacked heat-exchanger and AC-evaporator together with a single air filter, we estimated roughly half the households with central AC also used space heating, for a total of roughly 140 million U.S. space-conditioning units with filters that require regular replacement.

Steven Byers, president of a major U.S. filter manufacturer, estimates that the typical housing unit changes air filters twice per year—around the seasonal changes from heating to cooling, and vice versa (20). Charles Kwiatkowski, vice president of a manufacturer that makes the top-selling filter brand, estimates nationwide annual sales of all brands of residential air filters at 350 million (21). Combining 350 million filters sold per year with our estimate of 109 million household filters suggests that the average housing unit changes its space-conditioning filter between 2 and 3 times per year. We reasoned from this that a conservative estimate would be that half or fewer filters are changed every month.

Tune up AC. We estimate current penetration at 30%. Nevada Power Company estimates that 20% of the households who applied for rebates on AC tune-ups were free riders (22), and we take this as one estimate of the current penetration. In 2008, when energy prices were exceptionally high, the National Energy Assistance Directors' Association surveyed American households regarding energy-efficiency measures taken that year and found that 50% of households reported tuning up their furnaces (AC tune-ups are not reported, but other efficiency measures showed similar adoption rates for heating and cooling) (23). Because 2008 was an exceptional year, we believe the typical rate of AC tune-ups is significantly lower than 50%. We take 30% as a reasonably conservative estimate. Sensitivity tests indicate that varying the current penetration of AC tune-ups between 20% and 50% changes the total PER and RAER for all actions by less than 1.4 MTC.

Routine auto maintenance. Regular oil changes. We estimate the current penetration to be 51%, according to news reports (24).

Oxygen sensor. We estimate the current penetration to be 51%, according to news reports (24).

Remove excess weight. Because we could find no research data on the current penetration of this action, we subjectively estimated it at 70%, meaning that 30% of cars have at least 100 lb of excess weight that could be removed.

Maintain recommended tire pressure. We estimate the current penetration to be 51%, according to news reports. (24)

A: Adjustment of Equipment. *Laundry temperature.* We estimate current penetration at 91%. Table HC2.10 of RECS 2005 (2) reports that of the 91.8 million households that use a clothes washer, 85.1 million use a setting of 'warm' or 'cold' for the wash cycle, yielding a penetration rate of 92.7%. Of the 91.8 million households that use a clothes washer, 72.0 million use a setting of 'cold' for the rinse cycle, yielding a penetration rate of 78.5%. We averaged these 2 percentages (85.6%). We raised the resulting figure by 5%, to account for rising penetration between 2005 and 2008, and rounded up to 91%.

Water heater temperature. We estimate current penetration at 20%. Most U.S. states have building/plumbing codes that require that plumbers and building owners set water heater temperatures to deliver water to faucets and showerheads at no more than 120°F. However, these codes generally do not limit water temperature at the water heater (25). Furthermore, a spot-check of 157 dwelling units in inner-city Memphis, TN revealed that 79% had hot tap water at or exceeding 130°F (26). We decided to place greatest weight on this finding, which was based on actual temperature measurements at taps, hence the value of 20% for current penetration.

D: Daily Use Behaviors. *Reduce standby electricity.* Because we could find no research data on the current penetration of this action, we estimated it at 20%, on the basis of the authors' judgments of the difficulty and the prevalence of the action.

Thermostat setbacks. Gas and electric heat. We estimate current penetration at 33%, according to data in Table HC2.5 of RECS 2005 (2), which reports data on household temperature settings during winter months for the first 3 conditions in section 1 above: (*i*) daytime setting when no one is home, (*ii*) daytime setting when someone is home, and (*iii*) setting during sleeping hours. For these conditions we calculated from table data the percentage of households making the corresponding thermostat setbacks for each of the 3 periods: (*i*) at or below 65°F (assuming a duration of 8 h), (*ii*) at or below 68°F (8 h), and (*iii*) at or below 65°F (8 h). We averaged the percentages for these 3 conditions to get 28%. We added 5% to account for increased adoption of these settings between 2005 and 2008.

Air conditioning. We estimate current penetration at 25%, according to data in Table HC2.7 of RECS 2005 (2), and using an analysis similar to the one for heating, above. RECS 2005 reports statistics on thermostat settings during summer months in households using central AC for the last 3 conditions in section 1 above: (*iv*) daytime setting when no one is home, (*v*) daytime setting when someone is home, and (*vi*) setting during sleeping hours. For these conditions, we calculated from table data the percentage of households making the corresponding thermostat setups: (*iv*) at or above 80°F (assuming a duration of 8 h), (*v*) at or above 78°F (8 h), and (*vi*) at or above 78°F (8 h). We averaged these percentages for the 3 conditions to get 20%. We added 5% to the estimated penetration to account for increased adoption between 2005 and 2008.

Line drying. We estimate that 8% of households line-dry their laundry during 5 months of the year. According to Table HC2.10 of RECS 2005 (2), of 91.8 million households with washing machines, 2.7 million have clothes dryers that they use only "infrequently or not at all," and 4.3 million households have a washer but no dryer. Combining these figures, 7.0 million households, or 7.6% of households with washing machines dry naturally, and we rounded this figure to 8%. We did not increase this figure to update from 2005 to 2008 because of evidence that tens of millions of households are prohibited by private homeowners' association rules from line drying (27).

Driving behavior. *Slower acceleration, unnecessary braking.* We estimate current penetration at 10%, according to the only source we could find (28).

Maintain 55 mph speed for highway driving. We estimate current penetration at 22%. We began with a review of top speed limits in each state and a tabulation of vehicle miles traveled (VMT) in each state, indicating that 19% of highway vehicle miles traveled in the U.S. are in states with a top speed limit of 55 mph or less (29, 30). A study of traffic speeds found that for states with a 65 mph urban interstate speed limit, a significant majority of drivers adhere closely to the speed limit (31). To account for fast drivers in states with speed limits of 55 mph or less, we assume a normal distribution of driving speeds, and matching the mean to the speed limit, we include all drivers below the mean and one half of a standard deviation above it (69% of the 19% of VMT); for states with faster speed limits, we include a 10% estimate of drivers traveling at 55 mph or below (10% of the remaining 81% of VMT). Rounding up to the next integer, the result is a conservative 22% penetration estimate.

Reduce idling. Recent survey data yield the estimate that 47% of drivers regularly idle unnecessarily in nontraffic situations (warming up excessively, waiting for passengers, or queuing in drive-through lanes) (32).

Carpooling and trip chaining. *Carpooling.* We estimate current penetration at 5%. In 2000, 113 million people commuted to work in a private vehicle (33), which accounts for 60% of the private vehicles in the United States. A 2005 survey found that 8% of commuting involved multiple passengers (34). Given these figures, we estimated a current penetration for carpooling of 4.8% (8% of 60%), which we rounded to 5%. We did not adjust this figure for changes between 2005 and 2008 because we do not perceive a trend for this action.

Trip chaining. We could not find reliable data on trip chaining but estimate a current penetration of 5% on the assumption that trip-chaining is similar to car pooling. For very small penetrations, such as this, our calculations exhibit very little sensitivity to the exact penetration.

Potential Emissions Reductions

We define PER as the reduction in emissions that would be achieved if the penetration were increased from its current level to 100% (i.e., if everyone in the relevant population who is not already performing the action in question would adopt it). The basic formula is $\text{PER} = (1 - P)\, E\, X_{\text{base}}$, where P is the current penetration of the action, E is the fractional emissions reduction from performing the action, and X_{base} is the base national emission rate from the behavior in question (see "Base emissions" in *Reasonably Achievable Emissions Reduction* for an explanation). For example, for replacing an older refrigerator with a current Energy Star compliant model, the current penetration is 27%, the fractional emissions reduction is 40%, and the base emissions are 36.4 MtC, so PER is 10.6 MtC. (Note that there are no double-counting corrections for refrigeration.)

The emissions factors E used in the PER calculations are corrected for double-counting assuming 100% penetration of all relevant actions. The base emissions rates X_{base} are computed using double-counting corrections appropriate to current penetration rates. See "Calculating double-counting corrections" and "Base emissions" in *Reasonably Achievable Emissions Reduction* for details.

We consider the relevant population for an action to be those who could potentially adopt it. For replacing plasma televisions with LCD or rear-projection televisions, the relevant population is the owners of plasma televisions; for annual tune-ups of air conditioners, the relevant population is households with air-conditioners; and so forth. This section identifies the basis of the estimates of PER displayed in column 4 of Table 1 of the main article. Estimates of the relevant populations and the total national emissions from each source are explained in *Baseline Energy Use and Emissions*.

Space heating and cooling calculations depend on the number of heating and cooling degree days. Calculations of efficiency gains were performed using spreadsheets from the U.S. government's Energy Star web site, which we modified to use national average numbers of heating and cooling degree days, as reported by the National Climatic Data Center, instead of city-specific degree days (35–38).

W: Weatherization and Upgrades of Home Heating and Cooling Systems. The 5 actions in this category yield a combined PER of 37.4 MtC, or 6.0% of individual/household (I/H) emissions.

Weatherization. The 3 weatherization actions, combined, have a PER of 25.2 MtC, or 4.0% of I/H emissions.

Seal drafts. A typical home can reduce annual heating and cooling energy use by 10% by sealing drafts (1), so PER is 3.7 MtC, or 0.6% of I/H emissions. Greater savings may well be achievable if the best available technique, the use of a blower door, is used to detect the drafts. However, we do not consider the use of this technique compatible with our high plasticity estimates. We see a tradeoff between greater plasticity and the greater savings possible with blower doors.

Adequately insulate attic space. Estimates of energy savings from installing or upgrading attic insulation vary greatly, with estimates ranging from approximately 20–40% of home heating energy (1, 39). We make the relatively conservative estimate that insulating attics could reduce household energy use by 25%, which yields a PER of 15.1 MtC, or 2.4% of I/H emissions.

Replace single-paned windows. Replacing single-paned windows with multipaned windows with low-emissivity coatings can reduce heating and cooling energy consumption by 15% (1), which yields a PER of 6.4 MtC, or 1.0% of I/H emissions.

HVAC equipment. The 2 actions in this category yield a combined PER of 12.2 M5C, or 2.0% of I/H emissions.

Replace older furnace with Energy Star model. Replacing a 15-year-old 78% efficient gas or LPG furnace with a 92% efficient Energy Star furnace reduces CO_2 emissions by 15% (35). This yields a PER of 3.7 million MtC nationally for gas and 0.4 MtC for LPG furnaces. Replacing a 15-year-old 80% efficient oil furnace with an 87% efficient Energy Star furnace reduces CO_2 emissions by 8%, which yields a PER of 0.70 MtC nationally. We have not considered any benefits associated with new electric furnaces because there is likely little efficiency gain. According to the Energy Star web page, basic electric furnaces are already 95% or more efficient [using the AFUE (annual fuel utilization efficiency) measure of efficiency], where the Energy Star criterion is 85% or 90% for oil and gas, respectively (40). Thus, the total PER for replacing older furnaces would be 4.8 MtC, or 0.8% of I/H emissions.

Replace central AC unit with Energy Star model. We assume that non–Energy Star central AC units have an average seasonal energy efficiency ratio (SEER) of 10.4 and a 3-ton size and that they are replaced with Energy Star qualified SEER 16 units. This reduces emissions by 35.0% (36). It yields a PER of 7.4 MtC, or 1.2% of I/H emissions. The 10.4 baseline comes from averaging AC ages reported in RECS 2005, taking ACs sold before 1994 to have SEER 9, those sold between 1994 and 2005 as having SEER 10 (the minimum allowed by federal regulations), and those sold after 2005 as having SEER 13, as required by 10 CFR 430 (2001). We presume replacement of the existing model not with the minimum Energy Star efficiency of SEER 14 but with a more efficient SEER 16 model. There are many Energy Star rated central AC systems to choose from with efficiencies of SEER 16 and above, and several manufacturers even offer systems with SEER 20 and above (41).*

E: Equipment Upgrades. The 7 actions in this category yield a combined total of 85.8 MtC, or 13.7% of I/H emissions.

Low-flow showerheads. Federal standards specify a maximum flow rate of 2.5 gpm for showerheads. Seventy-six percent of households currently use showerheads that satisfy this standard, and 10% significantly exceed this standard with showerheads around 2.0 gpm. We estimate that the 24% of showerheads that do not meet federal standards have average flows of 3.25 gpm (7).

Replacing noncompliant 3.25-gpm showerheads with 2.5-gpm ones would reduce annual household energy consumption for water heating by 138 kWh (4.9%) in homes using electric water heaters and 0.61 million BTU (MBTU) (2.6%) in homes using gas water heaters.† We assume that the savings in the small number of homes with oil or LPG water heaters is similar to that for gas heaters.

Replacing 2.5-gpm showerheads with 2.0-gpm showerheads would save another 92 kWh (3.3%) for electric water heating and 0.41 MBTU (1.7%) for gas.

Because 76% of the nation's households already use 2.5-gpm showerheads, we take a weighted average of reductions from 3.25 to 2.0 and from 2.5 to 2.0, which yields $[(4.9\% + 3.3\%) \times 0.24 + (3.3\% \times 0.64)]/0.90 = 4.6\%$ reduction of emissions due to electric water heating and $[(2.6\% + 1.7\%) \times 0.24 + 1.7\% \times 0.66]/0.90 = 2.4\%$ reduction of emissions due to gas, oil, and LPG water heating. This yields a combined national PER of 1.4 MtC, or 0.2% of I/H emissions.

Efficient water heater: replace non Energy Star water heater with Energy Star model. Replacing a typical gas water heater with gas tankless or gas-condensing heater meeting the January 2009 Energy Star specifications would reduce energy consumption by 29% (42). Replacing a typical electric water heater with a tankless one would reduce energy consumption by 8.7%. Heat-pump electric water heaters currently on the market could reduce energy consumption by up to 55% over conventional electric models, but we do not consider them because they are currently only manufactured in very small numbers. This gives PER estimates of 4.8 MtC for gas heaters and 1.3 MtC for electric heaters. The total PER for gas and electric heaters combined is 6.1 MtC, or 1.0% of I/H emissions.

In addition, installing an insulating blanket on an older electric water heater would reduce energy consumption by 4–9% (43). We consider a 6% efficiency gain, which yields a PER of 0.6 MtC, or 0.1% of I/H emissions. Blankets are not recommended for gas heaters, so we only consider electric water heaters here.

The combined PER for replacing inefficient water heaters and installing insulating blankets is 6.7 MtC, or 1.1% of I/H emissions.

Appliances. The 3 actions replacing inefficient appliances with efficient Energy Star ones yield a combined PER of 14.7 MtC, or 2.3% of I/H emissions.

Replace large-screen plasma television with rear-projection or LCD unit. The average large-screen plasma television draws 339 W (44). The average large-screen LCD television draws 213 W, and the average large-screen rear-projection television draws 211 W. Replacing a plasma television with an LCD or rear-projection television would thus reduce emissions from those televisions by 38%, for a PER of 1.3 MtC, or 0.2% of I/H emissions.

Replace non–Energy Star refrigerator with Energy Star model. Replacing a conventional refrigerator purchased in 2001 with a current Energy Star model will reduce energy consumption by 40% (45–47). This gives a PER of 10.6 MtC, or 1.7% of I/H emissions.

Replace non–Energy Star clothes washer with Energy Star model. According to the EPA, purchasing a new Energy Star clothes washer instead of a conventional model will reduce direct electricity consumption by the clothes washer by 31%, reduce water consumption (and thus energy use to heat water for washing) by 55%, and remove water more efficiently during the spin cycle to reduce energy consumption by clothes dryers by ≈10% (48, 49). These contributions to energy savings combine to give a PER of 2.7 MtC, or 0.4% of I/H emissions. Changing the temperature of the wash cycle is considered separately from the efficiency of the Energy Star appliance.

LRR tires: Replace high rolling resistance tires on car with LRR ones. Using LRR tires in place of conventional ones can improve fuel economy by 4.5% (1, 50). This gives a PER of 7.4 MtC, or 1.2% of I/H emissions.

Fuel efficient vehicle. Replacing a household vehicle with a fuel economy of 20.8 mpg (the average adjusted composite EPA fuel economy for all automobiles and light trucks in model year 2008) with one that gets 30.7 mpg will reduce emissions by 32%. This yields a PER of 56.3 MtC, or 7.1% of I/H emissions. The 30.7 mpg figure (average adjusted composite DOE/EPA fuel economy) is based on the set of the 26 most fuel-efficient vehicles from the "Fuel Economy Leaders: 2009 Model Year" section of DOE/EPA's *Model Year 2009 Fuel Economy Guide*. The set excludes passenger vans and cargo vans but includes the economy leaders in all other categories of vehicle, including 2-seater, minicompact, subcompact, compact, and large cars, as well as small station wagons, minivans, small sport utility vehicles, and small pick-up trucks. Again, the subset consists of the 26 most fuel-efficient motor vehicles that can be bought in the United States for the 2009 model year. The calculation does not assume a shift in the types of vehicles in the U.S. fleet.

The U.S. government has mandated an increase of fleet-average fuel economy to 35 mpg by 2025 (51). Even without additional policies, such as we advocate here, this will reduce emissions from personal driving. However, even with a rising average fuel economy, consumers will continue to have opportunities to purchase cars and trucks that have significantly above-average economy within their class. Consider that the European Union has adopted a standard requiring fleet-average fuel economy to reach 45.5 mpg by 2012 and 57.5 mpg by 2020, so there is clearly ample room for consumers to purchase cars

*Query to ref. 41 returned 3,744 records for actively marketed residential AC units with 3-ton capacity and SEER 16+ and 57 records for 3-ton units with SEER 20+.

†According to Biermayer (7), replacing noncompliant showerheads with compliant ones reduces water flow by 0.75 gpm. The average household takes 0.75 showers per day, for 8 min per shower, at a water temperature of 105°F. Taking Biermayer's throttling factor of 2/3, the water savings would be 1,233 gallons per year. Energy use is 0.112 kWh/gallon for electric water heaters and 498 BTU/gallon for gas water heaters (these measures are per gallon of mixed water at 105°F, not per gallon of hot water from the heater). This produces annual energy savings of 138 kWh and 0.614 MBTU for electric and gas water heaters, respectively.

and trucks that significantly exceed the U.S. CAFE standard (52). Thus, we take a snapshot of current vehicle fuel economy for these calculations and anticipate that even with changing federal standards, the opportunity to reduce emissions through choice of vehicles will persist.

Efficient lighting. The text does not include an estimate of PER for lighting because of the mandated phaseout of incandescent lighting by 2014. The PER estimate in the main paper was calculated as follows: the current penetration of compact fluorescent lights was estimated at 36%. Table HC2.13 of RECS 2005 reports on the total number of light bulbs and the number of energy-efficient light bulbs in each of 3 categories: those used 1–4 h per day, 4–12 h per day, and >12 h per day (53). We take a weighted average of the fraction of energy-efficient bulbs used in each category using weighting factors of 2, 8, and 14 h of daily usage, respectively, for the 3 categories, to arrive at a penetration of 31% for 2005. We increased this by 5% to account for rising penetration of compact fluorescent lights between 2005 and 2008.

EnergyStar compact fluorescent light bulbs use 75% less energy than conventional incandescent bulbs of the same brightness (54). Increasing penetration from 36% to 100% yields a PER of 30.2 MtC, or 4.8% of I/H emissions.

M: Maintenance of Equipment. The 5 actions in this category yield a combined PER of 20.3 MtC, or 3.2% of I/H emissions.

Change HVAC air filters: Replace home ventilation filters for heating and AC every month in season. If household air filters are not changed regularly, the pores in the filter clog with dust, raising the pressure drop across the filter, decreasing air flow by up to 50% and reducing the efficiency of the heating and cooling equipment by as much as 30% (55). Laboratory measurements suggest that replacing air filters regularly reduces heating and cooling energy consumption by roughly 20% (56). It is not clear from the literature how clogged typical household filters are compared with the dirty filters used in the experiments, so we take a more conservative assumption that changing air filters monthly reduces heating and cooling costs by 15% as compared with replacing them twice a year. This yields a PER of 8.7 MtC, or 1.4% of I/H emissions.

Tune up AC: Annual professional inspection and tune-up of central AC. Regular professional tune-ups of home AC equipment can reduce energy consumption by 17–30% (22, 23, 57). We take the conservative (lower) end of this range, 17% reduction, which gives a PER of 3.0 MtC, or 0.5% of I/H emissions.

Routine auto maintenance. The following 3 routine maintenance actions yield a combined PER of 8.6 MtC, or 1.4% of I/H emissions.

Regular oil changes, tune-ups, and changing oxygen sensor at recommended intervals. Tuning up a car that is noticeably out of tune can improve fuel economy by an average of 4%. Fixing more serious problems, such as replacing a faulty oxygen sensor, can improve fuel economy by up to 40% (58). Using the correct grade of motor oil can improve fuel economy by 1–2% in comparison with even a slightly different grade. We consider that the average motorist performs some degree of regular maintenance, and mandatory emissions tests catch the worst problems, so we propose that more strict adherence to regular maintenance schedules could improve fuel efficiency by ≈5.5%. This yields a PER of 5.0 MtC, or 0.8% of I/H emissions.

Regularly remove excess weight from vehicle. Removing 100 lb of unnecessary weight from the vehicle (e.g., removing items from the trunk) improves fuel economy by 1–2% (59). Combining the lower, 1%, number with our estimate that 30% of vehicles carry unnecessary weight gives a PER of 0.6 MtC, or 0.1% of I/H emissions.

Maintain proper tire inflation. Inflating tires properly can improve fuel economy by 3.3% (60). This yields a PER of 3.0 MtC, or 0.5% of I/H emissions.

A: Adjustments of Equipment. The 2 actions in this category have a combined PER of 3.4 MtC, or 0.5% of I/H emissions.

Laundry temperature: Reduce hot water consumption by washing clothes on warm/cold cycle. If clothes are washed using a warm/cold cycle instead of a hot/warm cycle, the emissions associated with water heating for clothes washing are reduced by 75% if the water heater is set to 140°F or by 70% if the water heater is set to 120°F (61). Because we estimate that 80% of households have water temperature significantly higher than 120°F, we use a weighted average of the 2 reduction factors: 74%, which gives a PER of 0.5 MtC, or 0.1% of I/H emissions.

Water heater temperature: Set back water heater to recommended 120°F. Every 10°F reduction in a water heater reduces energy consumption by 3–5% (62, 63). Reducing hot water temperatures from 140°F to 120°F would thus reduce energy consumption by ≈8%, with a PER of 2.8 MtC, or 0.5% of I/H emissions.

D: Daily Use Behaviors. The 8 actions in this category have a collective PER of 85.7 MtC, or 13.7% of I/H emissions.

Reduce standby electricity. Standby electricity use affects all 111 million households that use electricity (63). We estimate average standby consumption per household at 440 kWh/yr (64). This estimate comes from a bottom-up analysis of appliance characteristics *ca.* 1996. Direct measurements of leakage electricity in California and Colorado give a range of 400–1,000 kWh/yr (65). However, it is not clear how these small direct-measurement studies generalize to the nation as a whole. A more recent estimate by Meier argues that 4–10% of total household electricity consumption, or 460–1,200 kWh/yr per household, is standby (66). Higher estimates may reflect the growth of electricity use for electronic equipment with standby uses since 1996. However, we have adopted the lower value of 440 kWh/yr per household as a conservative estimate.

Using the emissions factors described in "Emission factors" in *Baseline Energy Use and Emissions*, 440 kWh/yr yields 85 kg/yr carbon per household, or 9.5 MtC nationwide. Thus, 1.5% of national I/H emissions can be attributed to standby electricity. Eliminating all this usage seems unreasonable, but we estimate that a household could reduce standby usage by 90% through nonregulatory measures. Adopting appliances that satisfy the Energy Star criterion of consuming no more than 1 W in standby mode would reduce standby consumption by 80%. Even lower standby power consumption of 0.1 W seems feasible for the future (60). A 90% reduction of standby electricity yields a PER of 10.5 MtC nationally, or 1.5% of I/H emissions.

Thermostat setbacks. The EPA's programmable thermostat savings calculator spreadsheet provides a useful tool for calculating the impacts of both manual and automatically programmed setbacks (37). We modified the spreadsheet to use U.S. population-weighted heating and cooling degree days averaged over the 8 years of 2000–2007 (4,022 and 1,320 degree days, respectively) instead of individual cities (38). We use the same energy-saving action described in ref. 1: for heating, the consumer adopts a baseline indoor temperature of 72°F in the winter and adjusts it down by 7°F for 8 h at night and 4°F for 10 h during the day during heating season when someone is at home, or by 7°F for 10 h during the day when someone is not at home (leaving 6 h without a setback). For AC, the consumer adopts a baseline temperature of 73°F in the summer and adjusts the temperature up by 5°F for 8 h at night and 10 h during the day when someone is at home, or by 7°F when no one is home. We assume that the average house is occupied during 100% of daytime hours on weekends and 50% on weekdays. This reduces heating emissions by 12.6% and cooling emissions by 18.7%. The PER for thermostat setbacks is 10.2 MtC, or 1.6% of I/H emissions.

Line drying. A total of 20.3 million households use gas or propane clothes dryers, and 67.2 million use electric dryers (2). Electric clothes drying uses 1079 kWh/yr per household (67). Gas dryers consume a total of 0.07 quads per year nationally, which corresponds to 3 MBTU/yr per household (68). The total nationwide emissions are 15 MtC. Thus, the PER for line drying during 5 months of the year is 6.0 MtC, or 1.0% of I/H emissions.

Driving behavior. The 3 actions relating to driving behavior have a total PER of 24.1 MtC, or 3.9% of I/H emissions.

Reduce acceleration and deceleration rates. Aggressive driving in the United States can reduce fuel efficiency by 25–48% (69). Adjustments to the style of driving, such as optimal shifting or using cruise control, by aggressive drivers can improve fuel efficiency by 10% or more (potentially as much as 45%). The extent of very aggressive driving in the United States is unclear. A study of Dutch drivers by the Netherlands Organization for Applied Scientific Research reviews empirical studies of eco-driving training and concludes that "an average achievable effect of 10% seems reasonable" (70). This figure is echoed by a U.S.-based commercial provider of eco-driving feedback devices that reports average fuel savings of 7–11% (71). We consider a 10% reduction of fuel consumption (and consequently of CO_2 emissions) to be reasonably achievable by those who choose to drive efficiently. This would have a PER of 16.4 MtC, or 2.6% of I/H emissions.

Maintain 55-mph speed for highway driving. Reducing highway speeds to 55 mph in the United States would reduce fuel consumption on highways by 21% (69). Scaling this by the fraction of highway driving in the U.S. driving cycle yields potential savings of 3.2% reduction in average fuel consumption if drivers reduced average highway speeds to 55 mph (69). Reducing highway speeds has a PER of 4.5 MtC, or 0.7% of I/H emissions.

Reduce idling time. Carrico et al. (32) estimate that reducing unnecessary idling out of traffic (long periods warming up the car or waiting) could reduce emissions from personal vehicles by 4.3 MtC, or 0.7% of I/H emissions (15.8 million metric tons of carbon dioxide = 4.3 million metric tons of carbon). If we correct this for double-counting, we get a PER of 3.2 MtC, or 0.5% of I/H emissions.

We can also calculate from Carrico et al. that an individual driver could reduce emissions by 0.048 metric tons of carbon per year, or 3.7% of emissions from personal driving, by eliminating unnecessary idling. (This individual emissions reduction figure is not corrected for double-counting because it assumes this is the only action the driver takes.)

Carpooling and trip-chaining. Carpooling and trip-chaining yield a combined PER of 36.1 MtC, or 5.8% of I/H emissions.

Carpool by carrying at least 1 passenger for every commuting trip. Adding 1 person to every single-occupant commuting trip in the United States and Canada would reduce overall fuel consumption by 14% (69), which yields a PER of 24.2 MtC, or 3.9% of I/H emissions.

Combine errands to reduce errand mileage by half. If drivers reduce mileage driven to perform errands by 50% by combining multiple errands in a single trip, they would reduce emissions by 6.9% (1). This yields a PER of 11.9 MtC, or 1.9% of I/H emissions.

Reasonably Achievable Emissions Reduction

RAER differs from PER by incorporating estimates of the behavioral plasticity (the proportion of current nonadopters who would become adopters) under the most effective package of interventions that do not add regulations, whereas the PER describes emissions reductions that would be achieved with 100% plasticity. The most effective intervention varies with the action. The main text discusses these differences and provides our plasticity estimates. We calculate RAER for each behavior within a type and use the sum as RAER for the type.

Both RAER and PER estimates correct for double-counting due to interactions among actions that "overlap." For instance, if someone replaces a water heater with a more efficient model and also consumes less hot water, the emissions reduction is less than the sum of the savings from each action taken on its own.

For PER, double-counting corrections are performed assuming 100% penetration of every relevant action, whereas for RAER the corrections are performed using our estimates of penetrations for the target year. The next section uses year 10 as an example, but the identical logic applies to RAER calculations for other years.

Calculating RAER. The procedure for calculating RAER is as follows. (*i*) From the current (reported) emissions associated with an action, we calculate the emissions reduction already achieved by the current penetration of the action, correcting for double-counting (interactive relationships among actions already taken, as described above). (*ii*) We add the savings calculated in (*i*) to the current emissions to estimate the "base emissions" for the action, that is the emissions that would have been produced if the current penetration of the action were zero. (*iii*) From the base emissions, we calculate the emissions reductions due to the year-10 penetration of the actions under consideration, including corrections for double-counting. (*iv*) Subtracting the year-10 reductions calculated in (*iii*) from the base emissions calculated in (*ii*) yields the year-10 emissions. (*v*) RAER is the difference between the current emissions and the year-10 emissions calculated in (*iv*).

Calculating double-counting corrections. Sometimes 2 actions interact so that the total savings from adopting both measures is less than the sum of the savings from each measure taken separately. When 2 or more actions overlap in this way, we correct by combining the actions multiplicatively, as described below. Suppose action A improves the energy efficiency of a water heater by a factor E_A, and action B reduces hot-water consumption by a factor E_B. A household that adopts both actions would reduce its energy consumption by a factor $E_{\text{total}} = 1 - (1 - E_A) \times (1 - E_B)$. We will call this effect "multiplicative" in contrast to the combination of independent (noninteracting) efficiency improvements, which combine additively for $E_{total} = E_A + E_B$.

When the penetration for action A is p_A and the penetration for action B is p_B, we must consider to what extent A and B are correlated so that the same people who adopt one adopt the other—in other words, we must know what the penetrations are for A alone, B alone, and A and B combined. To rigorously treat the interactions among the large number of behaviors we consider in this article, we would need to consider all possible combinations of interacting actions, as well as the correlations among penetrations for the different actions. The mathematics of such a rigorous treatment are beyond the scope of this report and would be of limited use because in any event we do not know the correlations among the different penetrations.

We treat the question of double-counting using a simpler rubric: we consider the full range of possible emissions reductions. At one end of the range is the sum of reductions of each action taken separately, which would be the total if no one took more than 1 action. At the other end of the range, the maximum correction factor would apply if everyone adopting any action also adopted all other interacting actions. In this case, the emissions factor would be $E_{total} = 1 - [(1 - E_1)(1 - E_2)...(1 - E_n)]$. The actual emissions reduction must be somewhere between these values, so we interpolate between the 2 endpoints using the median of the penetrations for the interacting actions:

$$E_{total}(P) = P[1 - (1 - E_1)(1 - E_2)\ldots(1 - E_n)] + (1 - P)(E_1 + E_2 + \ldots + E_n),$$

where P is the median penetration.

For example, 7 different actions interact to affect emissions due to central AC: thermostat setbacks (18.7% emissions reduction), changing household air filters (15.0%), professional tune-ups (17.0%), purchasing a new Energy Star unit (35.0%), weather-stripping the house (10.0%), insulating the attic (25.0%), and installing high-efficiency, low-emissivity windows (15.0%). The first 4 interact multiplicatively, and the latter 3 interact additively with one another, with the sum of these (50%) interacting multiplicatively with the 4 other actions. Without correcting for double-counting, the total emissions reduction for someone performing all 7 actions would be 18.7% + 15.0% + 17.0% + 35.0% + 50.0% = 136%. In fact, someone performing all 7 actions would only save 1 − [(1 − 0.187) × (1 − 0.150) × (1 − 0.170) × (1 − 0.350) × (1 − 0.500)] = 81.4%. Thus, someone performing all 7 actions reduces emissions by only 60% of the sum of the actions taken individually. To correct for double-counting in a household that performs all 7 actions, we would multiply the raw emissions reduction for to each action by a correction factor of 60%.

The correction factor for an entire population, some of whom perform multiple actions and some of whom do not, will be somewhere between the extremes of 100% and 60%. Because we do not know the exact correlation among different actions and because a detailed and rigorous calculation is beyond the scope of this article, we estimate the correction factor by interpolating linearly between the 2 ends of the range, using the median penetration. For example, for year 10, the penetrations for the 7 actions for AC are 51%, 65%, 51%, 84%, 97%, 95%, and 96%. The latter 3 add, with an average penetration of 96%, so we take the median of 51%, 65%, 51%, 84%, and 96%. With a median of 65%, the correction factor for AC at year 10 is 0.65 × 60% + (1 − 0.65) × 100% = 74%. Thus, at year 10 the true emissions reduction for each action would be 74% of the raw reduction; so for instance, the emissions reduction due to thermostat setbacks would be 74% of 18.7%, or 13.8%.

Base emissions. The reason for calculating the base emissions as part of determining RAER is to take into account the fact that current emissions associated with an activity reflect a blend of households that have already adopted the action with those that have not. A household that has not yet adopted a given action will have a greater emissions reduction with that action than the national average household because the national average includes households that have already adopted the action and that therefore have a lower than average base of emissions for the action in question to reduce. To calculate a base rate of emissions that assumes that households have not adopted the emissions-reduction behaviors, we first calculate the emissions reduction already achieved due to the current penetration levels (these reductions are in comparison with what we call a base rate of emissions: what the national emissions would be if no one performed any of the actions under consideration—i.e., if all penetrations were zero). This calculation uses the double-counting corrections described above, performed using the current penetration estimates for the relevant actions.

Next, we calculate the zero-penetration base rate of emissions by adding the reductions due to current penetration to the current emissions as reported by the Energy Information Administration and the EPA.

To calculate the year-10 emissions reductions for an action, we multiply this base rate of emissions by the fractional reduction reported in the third section (*Potential Emissions Reductions*), corrected for double-counting using the year-10 penetrations.

Example calculation of RAER. Replacing inefficient refrigerators with current Energy Star models reduces emissions by 40%. Current penetration is estimated at 27%, and current emissions due to refrigeration are 32.4 MtC. We can express the current emissions X_0 as $X_0 = [P_0\ (1 - E_{E^*}) + (1 - P_0)]\ X_{base}$ and invert this to determine the base emissions $X_{base} = X_0/[P_0\ (1 - E_{E^*}) + (1 - P_0)]$ = 32.4 MtC/(0.27 × 0.60 + 0.73) = 36.4 MtC.

To calculate PER, we calculate emissions for 100% penetration: PER = $X_0 - (1 - E_{E^*})\ X_{base}$ = 10.6 MtC.

Emissions at year 10, when the penetration P_{10} is expected to be 85% is $X_{10} = [P_0\ (1 - E_{E^*}) + (1\text{-}P_0)]\ X_{base}$ = (0.85 × 0.60 + 0.15) × 36.4 MtC = 23.9 MtC. Thus, RAER10 due to adopting Energy Star refrigerators is (32.4 − 23.9) MtC = 8.5 MtC.

Note that because no other actions interact with refrigeration, there is no double-counting correction. If there were interacting actions affecting refrigeration, we would apply double-counting corrections to E_{E*} in calculating the base emissions level, energy savings at year 10, and the PER.

Double-Counting Interactions. ***Heating and AC.*** Improvements to the building envelope are considered additive because they remove independent paths for heat to leak out of the building. We assume that improving the attic insulation does not appreciably affect air leaks around windows and doors or radiative and conductive losses through window glass, so we add these 3 items.

Improving ventilation efficiency by replacing air filters combines multiplicatively with improvements to the furnace for an efficiency gain of 1 − (1 − $E_{furnace}$) × (1 − E_{filter}). Filters and high-efficiency ACs also combine multiplicatively.

Finally, we multiplicatively combine the 3 classes of improvement: envelope improvements, equipment efficiency improvements, and thermostat setbacks.

Hot water. Setting back the temperature of a water heater and purchasing an Energy Star water heater combine multiplicatively. Two actions curtail laundry demand for hot water: washing on warm/cold cycles and reducing water consumption per load by purchasing an Energy Star washer. These actions combine multiplicatively. Laundry curtailment combines additively with shower curtailment due to low-flow showerheads to give the total reduction of hot water consumption. Finally, the demand curtailment and heating efficiency combine multiplicatively.

Clothes drying. The effects of Energy Star washers and line-drying on energy consumption for drying clothes combine multiplicatively.

Driving. There are 2 classes of efficiency measures relevant to driving: fuel efficiency (new vehicle, regular maintenance, maintaining tire inflation, installing LRR tires, efficient driving practices, and lower highway speeds) and consumption curtailment (carpooling, trip-chaining, and reduced idling). Actions within the efficiency category combine multiplicatively, whereas actions within the curtailment category combine additively. Finally, we combine the 2 categories multiplicatively.

Baseline Energy Use and Emissions

Total Emissions. Total U.S. emissions of CO_2 in 2005 were 6.03 billion metric tons of CO_2, or 1.65 GtC (72). We take the individual and household share to be 38% of this, or 626 MtC (1).

Emission Factors. ***Electricity.*** U.S. average nonbaseload emissions are 1,569 lb CO_2/MHh = 0.194 kg C/kWh (73). This does not include line losses in the transmission and distribution of electricity. These losses have been estimated at 7.2% (74) and as ranging from 9.6% to 10.6% (75). Our analysis uses the low end of Vaninsky's range of estimates, 9.6%, as our correction for line losses. This raises the emissions factor for electricity to 0.215 kg C/kWh. For conversion between kWh and BTU, we take the energy content of the delivered energy and use a factor of 3,412 BTU/kWh (68).

Natural gas: 14.5 kg C/MBTU (76); fuel oil: 20.0 kg C/MBTU (76); LPG: 17.0 kg C/MBTU (76); gasoline: 2.19 kg C/gallon (76).

Standby Electricity Use. As noted in *Potential Emissions Reductions* ("Reduce standby electricity"), we estimate emissions from standby electricity use in homes at 94.5 kg C per year per household, which sums to 10.5 MtC nationwide for the 111 million households using electricity, or 1.7% of I/H emissions.

Space Heating. We estimate energy consumption and emissions associated with space heating from the Energy Information Agency's *Annual Energy Outlook 2007* (68). We consider emissions associated with all types of housing, although it might be useful in future work to disaggregate owner-occupied housing from rental housing and single-family from multifamily buildings.

In all, 33.7 million households use central electric heat (forced-air furnace or heat pump). These houses use a total of 0.40 quads of electricity for space heating (68). One quad corresponds to 293 billion kWh, for total national emissions of 25 MtC, or 4.0% of I/H emissions. The average house using electric space heating consumes 3,479 kWh/yr and is responsible for 747 kg C/yr. A total of 58.2 million households heat with natural gas. Annual national natural gas consumption for residential space heating totals 3.52 quads per year and produces emissions of 51 MtC, or 8.1% of I/H emissions. The average household heating with natural gas uses 60 MBTU/yr and emits 875 kg C/yr. Six million households heat with LPG. Annual national LPG consumption for residential space heating totals 0.26 quads per year and produces 4.4 MtC emissions, or 0.7% of I/H emissions. The average household heating with LPG uses 42 MBTU/yr and emits 736 kg C/yr. In all, 7.7 million households heat with distillate fuel oil. Annual national oil consumption for residential space heating totals 0.82 quads per year and produces 16.4 MtC, or 2.6% of I/H emissions. The average household heating with oil uses 102 MBTU/yr and emits 2125 kg C/yr.

Total emissions from heating, representing 105.6 million households, are 97 MtC, or 15.5% of national I/H emissions. The average household emissions from heating are thus 918 kg C/yr.

Air Conditioning. We estimate emissions associated with AC from RECS 2005, Tables HC2.6 and US14: 65.9 households have central AC equipment (2). Another 28.9 million have window or wall units, but we restrict this analysis to those houses with central AC. The average household with central AC uses 9.8 MBTU, or 2,872 kWh/yr of electricity for AC (77). Annual emissions from AC are 617 kg carbon per household. National emissions are 41 MtC/yr, or 6.5% of total I/H emissions.

Total HVAC comprises heating, AC, and operation of a central ventilation blower, also called a furnace fan, which consumes 500 kWh/yr (67). The blower is responsible for 107 kg C/yr per household, 8.2 MtC nationwide, and 1.3% of I/H emissions. Together, heating, AC, and furnace fans account for 146 MtC/yr nationwide (23.3% of I/H emissions).

Water Heating. In all, 43.1 million housing units use electricity for the main energy source to heat water, with the average household using 2,814 kWh/yr to heat water (2). Emissions are 604 kg C/yr per household, totaling 26 MtC/yr, or 4.2% of I/H emissions.

A total of 58.7 million households use natural gas as their principal energy source to heat water, with the average household using 24 MBTU (76). Emissions are 349 kg C/yr per household, 20 MtC/yr, or 3.3% of I/H emissions. A total of 4.0 million households use LPG as their principal energy source to heat water, with the average household using 25 MBTU. Emissions are 432 kg C/yr per household, totaling 1.7 MtC/yr, or 0.3% of I/H emissions. Four million households use fuel oil as their principal energy source to heat water, with the average household using 28 MBTU. Emissions are 559 kg C/yr per household, totaling 2.2 MtC/yr, or 0.4% of I/H emissions.

Total emissions from water heating are 50 MtC nationwide, or 8.1% of I/H emissions.

Laundry. ***Dryers.*** A total of 20.3 million households use gas or propane clothes dryers, and 67.2 million use electric dryers (2). Clothes drying uses 1,079 kWh/year per household (67). Gas dryers consume a total of 0.07 quads per year nationally, which corresponds to 3 MBTU/year per household (68). The total nationwide emissions are 17 MtC or 2.7% of I/H emissions.
Washers. A total of 91.8 million households have a clothes washer. A typical clothes washer uses approximately 80 kWh/yr running its motor, which emits 17 kgC per household per year, 1.6 MtC nationally, or 0.3% of I/H emissions (78, 79). The washing machine (assuming it is a 1998–2003 model) also uses 240 kWh/yr for heating water in an electric hot water heater, or 1.4 MBTU/yr for a gas heater. This represents approximately 5.6% of water heating energy for electric heaters and 7.4% of water heating for gas heaters. The combined emissions from water heating for clothes washers total 3.0 MtC/yr, or 0.5% of national I/H emissions.
Total. Total emissions for laundry washing and drying are 21 MtC/yr, or 3.4% of national I/H emissions.

Refrigeration. A total of 111.0 million households have a refrigerator (80). Refrigeration (including freezers) consumes 1,359 kWh/yr in the average household, for a total of 0.52 quads per year nationwide. This produces 292 kg carbon per household, with total national emissions of 32 MtC, or 5.2% of I/H emissions.

Televisions. A total of 109.7 million American households have color televisions (2), but large-screen plasma televisions are responsible for a large share of total television energy use. Industry estimates state that in 2007 approximately 35% of U.S. households owned at least 1 large-screen HDTV set, with annual sales of approximately 20 million, from which we extrapolate approximately 60 million HDTV sets at the end of 2008. Approximately 23% of HDTV sales are large-screen plasma sets, which suggests a total of approximately 14 million. The average large-screen plasma television consumes 339 W (44). On the basis of reported usage from the RECS 2005 survey, we estimate that the average household has the television on an average of 7.0 h per day (2).[‡] Thus, large-screen plasma televisions consume 861 kWh/year, with emissions of 185 kg carbon per set and total national emissions of 11 MtC, or 1.8% of I/H emissions.

Household Vehicles. A total of 191 million household vehicles are regularly used for personal (i.e., nonbusiness) transportation in the United States and use an average of 592 gallons of gasoline (or its equivalent in diesel) per year for personal transportation (60). This results in the emission of 1,300 kg carbon per vehicle, which totals 248 MtC nationwide, or 39.7% of I/H emissions.

[‡]On weekdays, 49.1% of the population reports that the television is on 1–3 hours per day, 46.0% reports the television on "most of the day," and 8.4% reports the television is "on all the time." On weekends, 35.9% reports 1–3 hours, 56.4% on most of the day, and 10.1% on all the time. Taking 2 hours as typical use for the 1–3-hour group, 8 hours typical of the "most of the day" group, and 24 hours for the "on all the time" group, we find an average of 6.9 hours per day, during the week.

1. Gardner GT, Stern PC (2008) The short list: The most effective actions U.S. households can take to curb climate change. *Environment* 50:12–25.
2. Energy Information Administration (2008) 2005 Residential Energy Consumption Survey: Household characteristics tables (Table HC2.4). Available at http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005html. Accessed October 4, 2009.
3. U.S. Environmental Protection Agency (2005) ENERGY STAR unit shipment and market penetration report: Calendar year 2004 summary. Available at http://www.energystar.gov/ia/partners/downloads/2004_USD_Summary_Report.pdf. Accessed May 25, 2009.
4. U.S. Environmental Protection Agency (2006) ENERGY STAR unit shipment and market penetration report: Calendar year 2005 summary. Available at http://www.energystar.gov/ia/partners/downloads/2005_USD_Summary_Report.pdf. Accessed May 25, 2009.
5. U.S. Environmental Protection Agency (2007) ENERGY STAR unit shipment and market penetration report: Calendar year 2006 summary. Available at http://www.energystar.gov/ia/partners/downloads/2006_USD_Summary_Report.pdf. Accessed May 25, 2009.
6. U.S. Environmental Protection Agency (2008) ENERGY STAR unit shipment and market penetration report: Calendar year 2007 summary. Available at http://www.energystar.gov/ia/partners/downloads/2007_Summary_Report.pdf. Accessed May 25, 2009.
7. Biermayer PJ (2005) *Potential Water and Energy Savings from Showerheads* (Lawrence Berkeley National Laboratory, Berkeley, CA), Publ No LBNL-58601.
8. U.S. Energy Information Administration (2004) Assumptions to the annual energy outlook. Available at http://www.eia.doe.gov/oiaf/archive/aeo04/assumption/residential.html. Accessed May 25, 2009.
9. Parks and Associates (2008) HDTV sales and penetration figures. Available at http://parksassociates.blogspot.com/2008/02/hdtv-penetration-and-sales-figures.html. Accessed May 25, 2009.
10. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2009) Low rolling resistance tires. Available at: http://www.afdc.energy.gov/afdc/vehicles/fuel_economy_tires_light.html. Accessed May 25, 2009.
11. U.S. Department of Energy (2009) *Fuel Economy Guide* (U.S. Environmental Protection Agency, Washington, DC), Publ No DOE/EE-D325.
12. U.S. Environmental Protection Agency (2008) *Light Duty Automotive Technology and Fuel Economy Trends: 1975–2008* (U.S. Environmental Protection Agency, Washington, DC), Publ No EPA420-R-08–015, pp iii, 6–9, Appendix C.
13. Davis SC, Diegel SW, Boundy RG (2008) *Transportation Energy Data Book, Edition 27* (U.S. Department of Energy, Washington, DC), Publ No ORNL-6981, Tables 3–7 and 3–8, pp 3-10, 3-11.
14. Davis SC, Diegel SW, Boundy RG (2008) *Transportation Energy Data Book, Edition 27* (U.S. Department of Energy, Washington, DC), Publ No ORNL-6981, Tables 4–17 and 4–18, pp 4-18, 4-19.
15. Davis SC, Diegel SW, Boundy RG (2008) *Transportation Energy Data Book, Edition 27* (U.S. Department of Energy, Washington, DC), Publ No ORNL-6981, Table 4–6, p 4–6.
16. Ward's Communications (2001–2008) *Ward's Automotive Yearbook, 2000 Through 2007* (Primedia, Norcross, GA).
17. Ward's Communications (2004) *Ward's Automotive Yearbook,* 2003 (Primedia, Norcross, GA).
18. U.S. Department of Energy (2003) *Fuel Economy Guide* (U.S. Environmental Protection Agency, Washington, DC), Publ No DOE/EE-0271.
19. Davis SC, Diegel SW, Boundy RG (2008) *Transportation Energy Data Book, Edition 27* (U.S. Department of Energy, Washington, DC), Publ No ORNL-6981, Tables 3–7 and 3–8, pp 3-10, 3-11.
20. Byers S (2008) Personal communication. Telephone interview with President, Air Filters, Inc. (Baltimore, MD), conducted by Russell Fraker, Vanderbilt University Law School, October 14, 2008.
21. Kwiatkowski C (2008) Personal communication. Telephone interview with Vice President, Flanders Corp. (Washington, DC), conducted by Russell Fraker, Vanderbilt University Law School, October 14, 2008.
22. Nevada Power Company (2009) Program Data Sheet, Residential High-Efficiency Air Conditioning, p 30; reprinted in Nevada Power Company (2009) Demand Side Plan, Vol 6, Book 2, p 143. Available at http://www.swenergy.org/news/2009-07-NV_Power_DSM_Plan_02.pdf. Accessed October 4, 2009.
23. National Energy Assistance Directors' Association (2008) Energy 2008 Energy Costs Survey, p 36. Available at http://www.neada.org/communications/surveys/EPC_Energy_Costs_Survey_Report_2008.pdf. Accessed October 4, 2009.
24. Reuters Business Wire (May 13, 2008) Fuel prices, economic concerns change how Americans drive and maintain their cars (Thomson Reuters, New York).
25. Wuori T (2003) Dangers associated with a forgotten appliance: Water heaters. *Burn Support News*, pp 14–16.
26. Sharp GB, Carter MA (1992) Prevalence of smoke detectors and safe tap-water temperatures among welfare recipients in Memphis, Tennessee. *J Community Health* 17:351–366.
27. Chaker AM (September 18, 2007) The right to dry. *Wall Street Journal*, p A1.
28. Schultz W (July 25, 2008) Would you drive 55? Available at http://www.time.com/time/nation/article/0,8599,1826694,00.html. Accessed July 29, 2009.
29. Insurance Institute for Highway Safety (2009) *Speed Limit Laws* (IIHS, Arlington, VA).
30. Bureau of Transportation Statistics (2008) State transportation statistics 2007 (Table 5–3, p E-3). Available at http://www.bts.gov/publications/state_transportation_statistics/state_transportation_statistics_2007/pdf/entire.pdf. Accessed May 12, 2009.
31. Retting RA, Teoh E (2008) Traffic speeds on interstates and freeways10 years after repeal of national maximum speed limit. *Traffic Injury Prevention* 9:119–124.
32. Carrico AR, Padgett P, Vandenbergh MP, Gilligan J, Wallston KA (2009) Costly myths: An analysis of idling beliefs and behavior in personal motor vehicles. *Energy Policy* 37:2881–2888.
33. McGuckin N, Srinivasan N (2003) Journey to work: Trends in the U.S. and its major metro areas 1960–2000 (Publ No FHWA-DP-03–058). Available at http://www.fhwa.dot.gov/ctpp/jtw/. Accessed May 12, 2009.
34. Langer G (February 13, 2005) Poll: Traffic in the United States. *ABC News.*
35. U.S. Department of Energy (2008) Life cycle cost estimate for an ENERGY STAR qualified residential furnace (Excel spreadsheet, updated by DOE July 2008, modified by the authors to use national average heating degree days). Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_Furnaces.xls. Accessed March 13, 2009.
36. U.S. Department of Energy (2008) Life cycle cost estimate for ENERGY STAR qualified central air conditioner(s) (Excel spreadsheet, updated by DOE August 2008, modified by the authors to use national average cooling degree days). Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_CAC.xls. Accessed March 13, 2009.
37. U.S. Department of Energy (2008) Life cycle cost estimate for ENERGY STAR qualified programmable thermostats (Excel spreadsheet, updated August 2008, modified by the authors to use national average cooling and heating degree days). Available at http://www.EnergyStar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calculator-ProgrammableThermostat.xls. Accessed March 13, 2009.
38. National Climatic Data Center (2008) Heating and cooling degree day data. Available at http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html#51overview. Accessed March 13, 2009.
39. Rocky Mountain Institute (2004) Home energy briefs #3: Space cooling. Available at: http://www.rmi.org/images/other/Energy/E04–13_HEB3SpaceCool.pdf. Accessed May 25, 2009.
40. U.S. Department of Energy (2009) Energy savers: Furnaces and boilers. Available at: http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530. Accessed May 25, 2009.
41. Consortium for Energy Efficiency (2009) CEE verified directory of air conditioning equipment database. Available at http://www.ceedirectory.org/ceedirectory/pages/ac/cee/defaultSearch.aspx. Accessed March 15, 2009.
42. U.S. Department of Energy (2009) ENERGY STAR Residential Hot Water Heaters: Final Criteria Analysis. Available at http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/WaterHeaterAnalysis_Final.pdf. Accessed May 25, 2009.
43. Rocky Mountain Institute (2006) Home energy briefs #5: Water heating. Available at http://www.rmi.org/images/PDFs/HEBs/E04–15_HEB5_WaterHeat.pdf. Accessed May 25, 2009.
44. CNET (2008) The basics of TV power. Available at http://reviews.cnet.com/green-tech/tv-power-efficiency/ (updated April 10, 2009). Accessed May 25, 2009.
45. Meyers S, McMahon J, McNeil M (2004) *Realized and Prospective Impacts of U.S. Energy Efficiency Standards for Residential Appliances* (Lawrence Berkeley National Laboratories, Berkeley, CA), Publ No LBNL-56417.
46. U.S. Department of Energy (1997) *Energy Conservation Program for Consumer Products* (U.S. Department of Energy, Washington, DC), Publ No 10 CFR 430, 23102.
47. U.S. Department of Energy (2005) Technical report: Analysis of amended energy conservation standards for residential refrigerator-freezers. Available at http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrigerator_report_1.pdf. Accessed May 25, 2009.
48. U.S. Environmental Protection Agency (2008) Life cycle cost estimate for ENERGY STAR qualified residential clothes washer (Excel spreadsheet, updated August 2009). Available at http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/CalculatorConsumerClothesWasher.xls. Accessed March 3, 2009.
49. D&R International, U.S. Department of Energy (2008) Clothes washer product snapshot. Available at http://www.EnergyStar.gov/ia/partners/reps/pt_reps_res_retail/files/CW_ProductSnapshot_May08.pdf. Accessed May 5, 2009.
50. American Council for an Energy-Efficient Economy (2007) Green driving tips. Available at http://www.greenercars.org/drivingtips.htm. Accessed May 25, 2009.
51. Energy Independence and Security Act of 2007 (2007) Public Law No 110–140.
52. Design Decision Wiki (2009) European Union vehicle emissions regulations. Available at http://ddl.me.cmu.edu/ddwiki/index.php/European_Union_vehicle_emissions_regulations#_note-8. Accessed June 22, 2009.
53. Energy Information Administration (2005) 2005 residential energy consumption survey (Table HC2.13). Available at http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/hc13lightingindicators/pdf/tablehc2.13.pdf. Accessed May 25, 2009.
54. U.S. Department of Energy and Environmental Protection Agency (2009) ENERGY STAR compact fluorescent light bulbs for consumers. Available at http://www.energystar.gov/index.cfm?c=cfls.pr_cfls. Accessed June 22, 2009.
55. Mei VC, Chen FC, Gao Z (2003) *Development of a Refrigerant Charge Indicator and Dirty Air Filter Sensor* (Oak Ridge National Laboratory, Oak Ridge, TN), Publ No ORNL/CON-489.
56. Lin CY, Hsiung SC, VerMa AK, Grossman GR (2004) Design and analysis of an air-filter sensor for a residential heating and cooling system. *Int J Mod Eng* 4. Available at http://www.ijme.us/issues/spring2004/Design_Analysis_AirFilter-21stEng.htm. Accessed February 14, 2009.
57. Neme C, Proctor J, Nadel S (1999) *Energy Savings Potential from Addressing Residential Air Conditioner and Heat Pump Installation Problems* (American Council for an Energy-Efficient Economy, Washington, DC), Publ No A992.
58. U.S. Department of Energy (2009) Keeping your car in shape. Available at http://www.fueleconomy.gov/feg/maintain.shtml. Accessed May 25, 2009.
59. U.S. Department of Energy (2008) Gas mileage tips: Driving more efficiently. Available at http://www.fueleconomy.gov/feg/driveHabits.shtml. Accessed May 25, 2008.
60. Vandenbergh M, Barkenbus J, Gilligan J (2008) Individual carbon emissions: The low-hanging fruit. *UCLA Law Rev* 55:1701–1758.

61. Rocky Mountain Institute (2004) Home energy briefs #6: Cleaning appliances. Available at http://www.rmi.org/images/PDFs/HEBs/E04–16_HEB6_CleanApps.pdf. Accessed May 15, 2009.
62. American Council for an Energy-Efficient Economy (2007) Consumer guide to home energy savings, condensed online version: Water heating. Available at http://www.aceee.org/consumerguide/waterheating.htm. Accessed May 25, 2007.
63. Energy Information Administration (2008) 2005 residential energy consumption survey: Summary statistics (Table US2). Available at http://www.eia.doe.gov/emeu/recs/recs2005/c&e/summary/pdf/tableus2.pdf. Accessed May 25, 2009.
64. Lebot B, Meier A, Anglade A (2000) *Global Implications of Standby Power Use* (Lawrence Berkeley National Laboratory, Berkeley, CA), Publ No LBNL-46019.
65. Meier AK (2001) *A Worldwide Review of Standby Power Use in Homes* (Lawrence Berkeley National Laboratory, Berkeley, CA), Publ No LBNL-49377.
66. Meier AK (2007) Standby power: Where are we now? (Lawrence Berkeley National Laboratory, slide presentation). Available at http://www.conae.gob.mx/work/sites/CONAE/resources/LocalContent/5343/1/AlanMeier1.pdf. Accessed January 4, 2008.
67. Energy Information Administration (2001) 2001 residential energy consumption survey: End use consumption of electricity. Available at http://www.eia.doe.gov/emeu/recs/recs2001/enduse2001/enduse2001.html. Accessed May 25, 2009.
68. Energy Information Administration (2007) *Annual Energy Outlook 2007* (U.S. Department of Energy, Washington, DC), Publ No DOE/EIA-0383.
69. International Energy Agency (2005) *Saving Oil in a Hurry* (Organization for Economic Cooperation and Development, Paris).
70. Smokers R, et al. (2006) *Review and Analysis of the Reduction Potential and Costs of Technological and Other Measures to Reduce CO_2-Emissions from Passenger Cars* (TNO Science and Industry, Delft, The Netherlands), Publ No 06.OR.PT. 040.2/RSM.
71. GreenRoad Technologies (2008) *Is Safe Driving More Economical? Driver Safety and Fuel Consumption* (GreenRoad Technologies, Redwood Shores, CA).
72. Energy Information Administration (2008) *Emissions of Greenhouse Gases in the United States* (U.S. Department of Energy, Washington, DC), Publ No DOE/EIA-0573.
73. U.S. Environmental Protection Agency (2008) eGRID 2008, version 1.0, year 2005 summary tables (p 6). Available at http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_0_year05_SummaryTables.pdf. Accessed May 26, 2009.
74. U.S. Climate Change Technology Program (2003) *Technology Options for the Near and Long Term* (U.S. Climate Change Technology Program, Washington, DC), Publ No DOE/PI-0002, p 34.
75. Vaninsky A (2006) Efficiency of electric power generation in the United States: Analysis and forecast based on data envelopment analysis. *Energy Economics* 28:326–338.
76. U.S. Environmental Protection Agency (2008) *Inventory of Greenhouse Gas Emissions and Sinks, 1990–2006* (EPA, Washington, DC), Publ No 430-R-08–005.
77. Energy Information Administration (2007) Residential energy consumption survey 2005: Consumption and expenditure tables. Available at http://www.eia.doe.gov/emeu/recs/recs2005/c&e/summary/pdf/tableus14.pdf. Accessed May 26, 2009.
78. U.S. Department of Energy (2000) Technical support document: Energy efficiency standards for consumer products: Clothes washers. Available at http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/chapter_10_nes.pdf. Accessed October 17, 2008.
79. U.S. Department of Energy (2000) Clothes washer national energy savings and shipments spreadsheet. Available at http://www1.eere.energy.gov/buildings/appliance_standards/residential/docs/2t_nes_shipments_spreadsheet.xls. Accessed March 2, 2009.
80. Energy Information Administration (2005) 2005 residential energy consumption survey: Consumption and expenditures tables (Table AP5). Available at http://www.eia.doe.gov/emeu/recs/recs2005/c&e/appliances&lighting/pdf/tableap5.pdf. Accessed May 26, 2009.