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ENERGY & ENVIRONMENT DIVISION

An Assessment of Future Energy Use and Carbon Emissions from U.S. Residences

J.G. Koomey, F.X. Johnson, J.E. McMahon, M.C. Orland, M.D. Levine, P. Chan, and F. Krause

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ABSTRACT

This paper explores residential energy futures and their associated carbon emissions using an engineering-economic end-use model. We present detailed input assumptions and output results for twenty-four cases, each representing a different combination of electricity supply mix, demand-side policy case, and carbon tax. We describe current and projected future energy use by end-use and fuel, and assess which end-uses are growing most rapidly in importance over time.

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I. INTRODUCTION

Forecasting models have been used extensively to assess the effect of government policy initiatives on residential energy use (Carlsmith et al. 1990, US DOE 1990, US DOE 1991/1992). Such analyses have taken on greater urgency because of concerns that greenhouse gas emissions from energy use may affect the global climate (US EPA 1990). This paper explores residential energy use and associated carbon emissions using an end-use model that relies heavily on engineering-economic data characterizing the cost of improving energy efficiency in appliances, space conditioning equipment, and building shells.

Section II describes the modeling methodology and assumptions used to create forecasts of residential energy use, including descriptions of the Lawrence Berkeley Laboratory's Residential Energy Model's (LBL REM's) structure and the required input data. Section III summarizes the key results of the modeling runs, and Section IV summarizes conclusions. Appendix A contains detailed tables and figures with the results of the many model runs completed for this report. Appendix B summarizes calculations of power plant busbar costs for comparison to the carbon taxes considered in this study.

II. MODELING METHODOLOGY AND ASSUMPTIONS

This section first outlines the important structural features of LBL REM and describes the sources and methods for compiling the necessary data.

LBL REM–general structure

LBL REM is an engineering-economic model that has been used for analyses of appliance efficiency standards since 1981 (McMahon et al. 1987). The model separates residential energy use into four fuels (electricity, natural gas, oil, other/LPG), three building types (single-family, multi-family, and mobile homes) and twelve end-uses (central heating, room heating, air conditioning, water heating, refrigeration, freezing, cooking, clothes drying, lighting, dish washing, clothes washing, and miscellaneous).

Exogenous inputs include housing starts, number of households, personal income, and energy prices. Baseline data inputs include base year appliance saturations, base year unit energy consumptions (UECs), base year efficiency factors, and econometrically estimated

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parameters describing the relationship between income, appliance purchases, and appliance usage. Outputs include projected energy use by end-use, projected UECs, projected efficiency factors, and projected fuel and capital expenditures in real dollars and present values.

LBL REM characterizes the decisions of the market for efficiency using an empirically-derived "market discount rate" that often exceeds the cost of capital (see Appendix A for details). In the reference case, the model calculates life-cycle costs (LCCs) using this discount rate and chooses the efficiency for new appliances that minimizes LCC. One can also force the model to calculate LCCs using a lower discount rate (e.g., 7% real), a procedure which in a crude sense allows the user to estimate the size of the techno-economic potential implied in the model inputs.

We used this procedure in some of the LBL REM runs in Appendix A, but we have concluded upon reflection that LBL REM (a model designed to estimate the impacts of appliance efficiency standards) is not well suited to such an exercise. Estimates of the techno-economic potential are best undertaken in the more traditional "conservation supply curves" framework as exemplified by Koomey et al. (1991) and enhanced by Brown (1993). We therefore admonish the reader to treat the "7% real discount rate" cases outlined in Appendix A with caution.

LBL REM–baseline data

The LBL REM defaults are assumed for equipment saturations, UECs, costs of efficiency improvements, and elasticities. The data in this model have been improved periodically over the past eleven years, using surveys of appliance manufacturers and home builders, and econometrically derived estimates of usage elasticities, cross-price elasticities, own-price elasticities, and other parameters. The most important data are documented in the technical support documents for the appliance efficiency standards impact analyses (US DOE 1988, US DOE 1989a, US DOE 1989b, US DOE 1990), as well as in supporting documents (Ruderman et al. 1987, Wood et al. 1989a, Wood et al. 1989b, Wood et al. 1989c). In LBL REM, electricity is converted to primary energy at 11,500 Btus/kWh.

Macroeconomic and fuel price assumptions

Appendix A shows the exogenous input assumptions in the Reference case taken from the National Energy Strategy's (NES's) Technical Annex 2 (US DOE 1991/1992) and the Annual Energy Outlook (US DOE 1991a) . The total number of households is projected to increase more than 40% over the 40 year analysis period, and household income is expected to grow 54% in real terms from 1990 to 2030. Natural gas, distillate oil, and LPG prices are projected to grow at annual rates from 1.0 to 1.9% in real terms, while real electricity prices are projected to grow only 0.3% per year over the analysis period.

III. RESULTS

Energy use by end-use in the reference case

Figure 1 show the end-use breakdowns over time for electricity. Space conditioning comprises 25-30% of primary electricity use in the residential sector, with water heating, refrigeration, and lighting contributing much of the rest. **Figure 2** shows that together, space heating and water heating account for more than 90% of natural gas energy use in residences, with space heating comprising about 70% of natural gas energy use, and water heating adding another 20%.

Figure 1: Residential Primary Electric Energy Use by End-Use, Reference Case (Case 1)

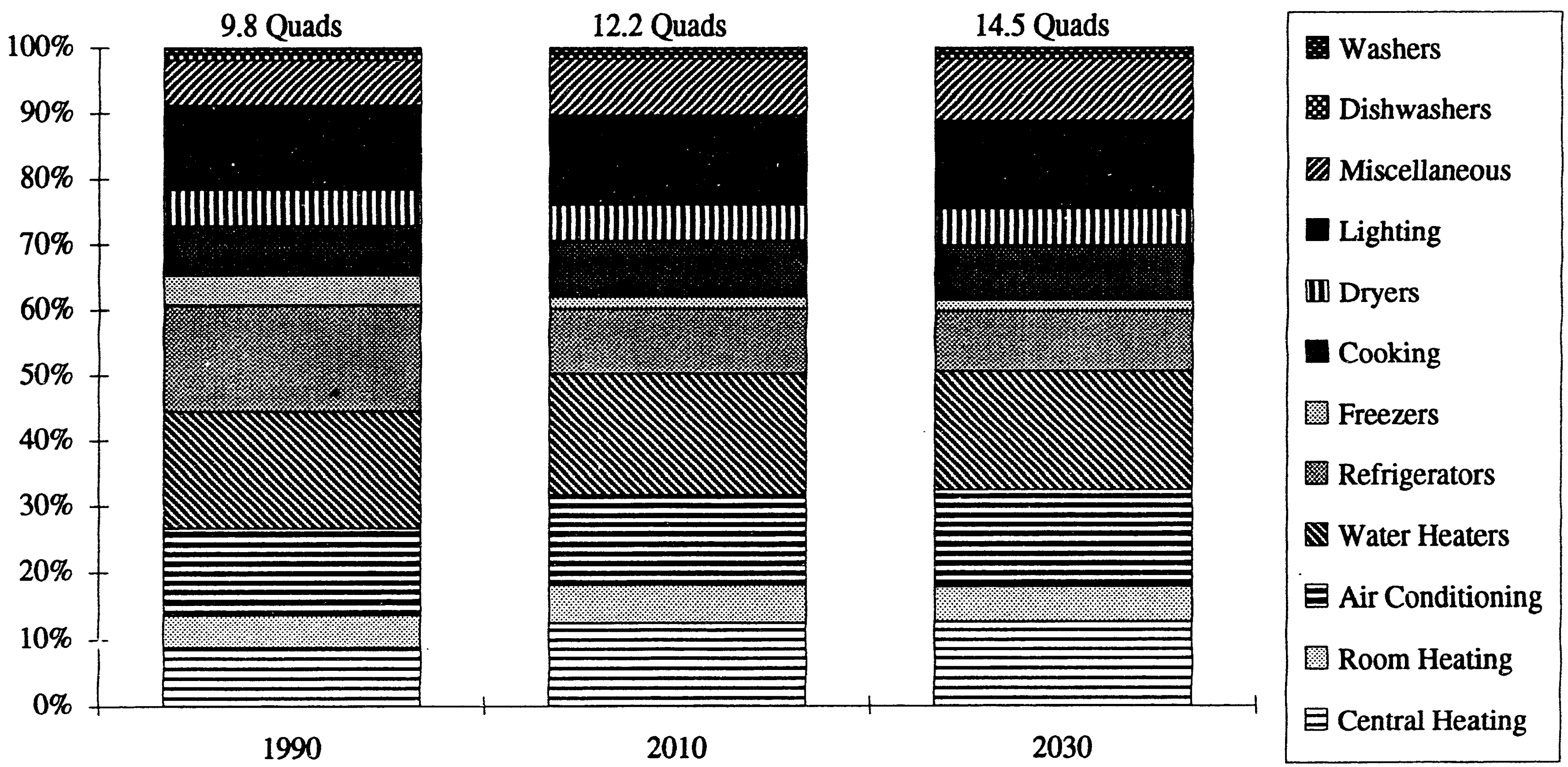
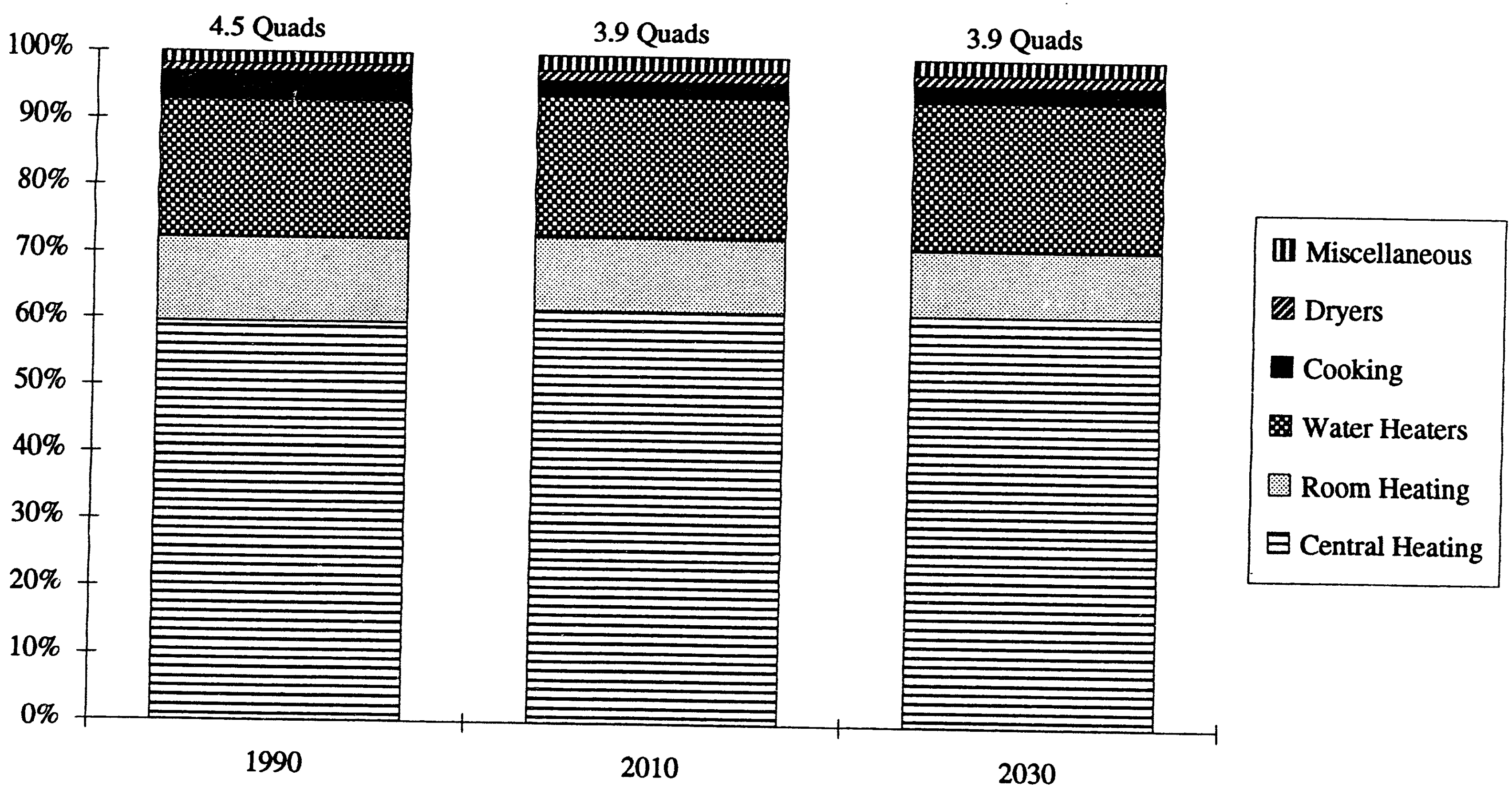


Figure 2: Residential Natural Gas Use by End-Use, Reference Case (Case 1)



The data used to construct these figures (from Appendix A) reveals that the five largest end-use fuel categories in 1990 (in primary energy terms) are, in order of decreasing importance, natural gas space heating (central plus room), electric water heating, electric resistance space heating, oil space heating, and natural gas water heating. Together these four end-uses comprise about 8 quadrillion Btus of resource energy in 1990, or about half of total residential primary energy use.

Figure 3 summarizes projected reference case growth in electricity demand by end use for the period 1990-2000. On the left hand Y axis is the average annual rate of growth in a given end use. Striped bars should be compared to this axis. On the right hand Y axis (which is associated with the solid bars) is the total reference case growth in primary electricity for a given end use, expressed in quads. This figure shows which end uses are growing fastest in percentage and absolute terms.

Average annual percentage electricity demand growth as forecasted by LBL REM is about 1.2%/year. End uses growing faster than this average include electric resistance and heat pump heating, heat pump cooling, cooking, and miscellaneous. Electricity use associated with refrigerator/freezers and freezers is declining at 2% to 5% per year, in large part because of the 1993 efficiency standards on these products.

In absolute terms, the largest contributors to electricity demand growth are electric resistance and heat pump heating, water heating, cooking, lighting, and miscellaneous. Refrigerator/freezers show a larger absolute decline in energy use than do freezers because refrigerator/freezers are more commonly used than are individual freezers. Part of the decline in freezer energy use is caused by lower saturations of these appliances in new homes. As shown in Appendix A, Table A.14. Total net growth in electricity demand from 1990-2000 is 1.25 quads of primary energy.

Effects of appliance efficiency standards

Appliance standards now exist for most residential end uses, including water heaters, furnaces, heat pumps, central air conditioners, room air conditioners, dishwashers, clothes washers, dryers, refrigerator/freezers, and freezers. **Figure 4** shows that savings from all appliance standards now in place (not including the 1994 EPACT showerhead and faucet standards) will total about 0.5 quads in 2000 and 0.8 quads in 2010. Year 2000 savings are 2.7% of forecasted primary energy use without standards, while 2010 savings are 4.5% of forecasted primary energy use.

About 3/4 of the projected savings are in electricity. The bulk of the electric savings are from refrigerator/freezers, freezers, and central air conditioners.

About 1/5 of the projected savings are in natural gas end-uses, with furnaces and water heaters accounting for almost all of these savings. Included in the water heating savings are reductions in hot water use brought about by standards on dishwashers and clothes washers in homes with gas water heaters.

Static menus of technology options

LBL REM projects future appliance efficiency choices based on life-cycle cost minimization using the market discount rate. The model assesses the life-cycle cost for a whole range of technology options, and chooses the option with the lowest LCC. This set of technology

Figure 3: Reference case changes in US residential primary electricity use 1990-2000, expressed in quads and as an average annual percentage rate

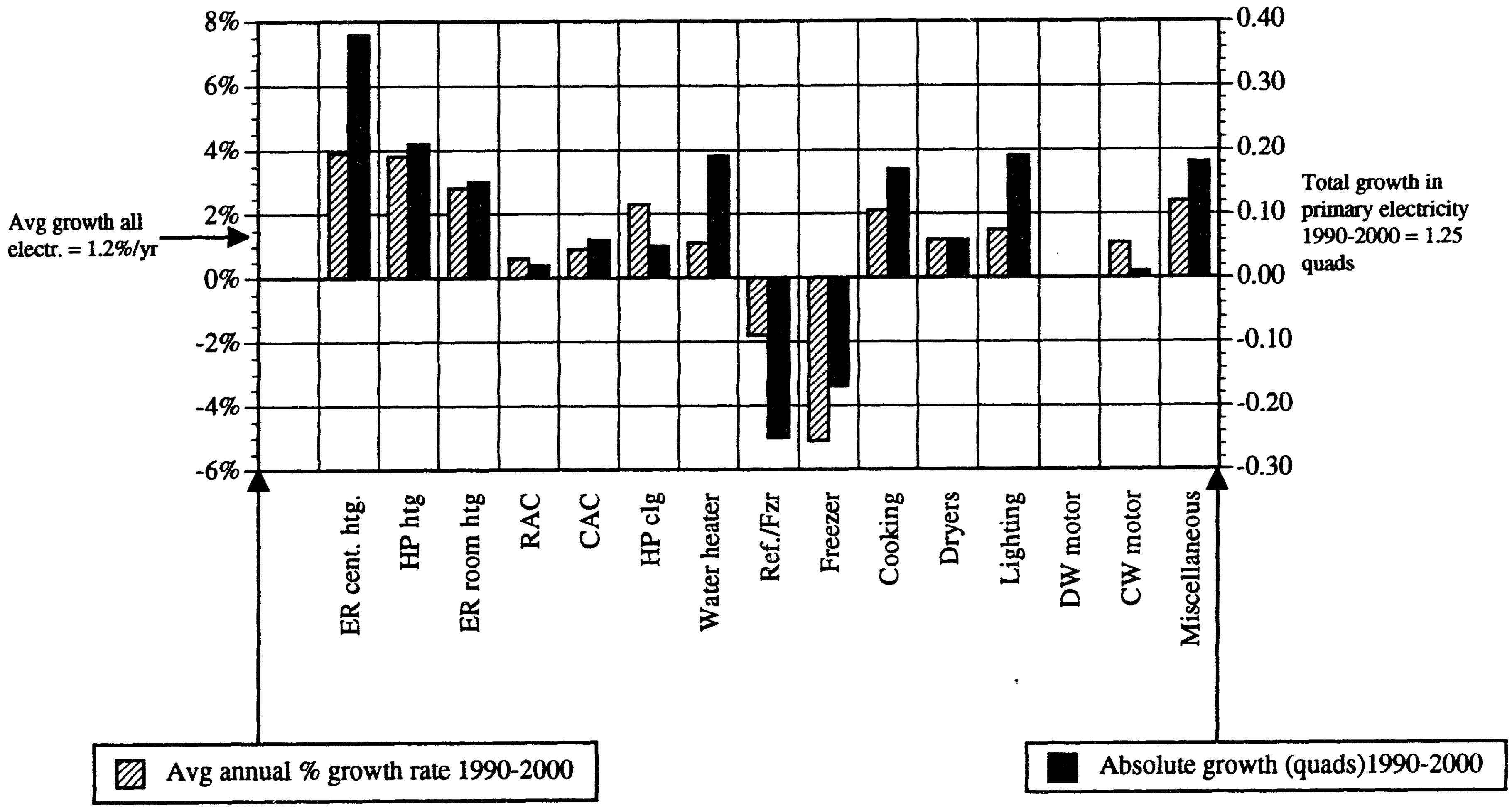
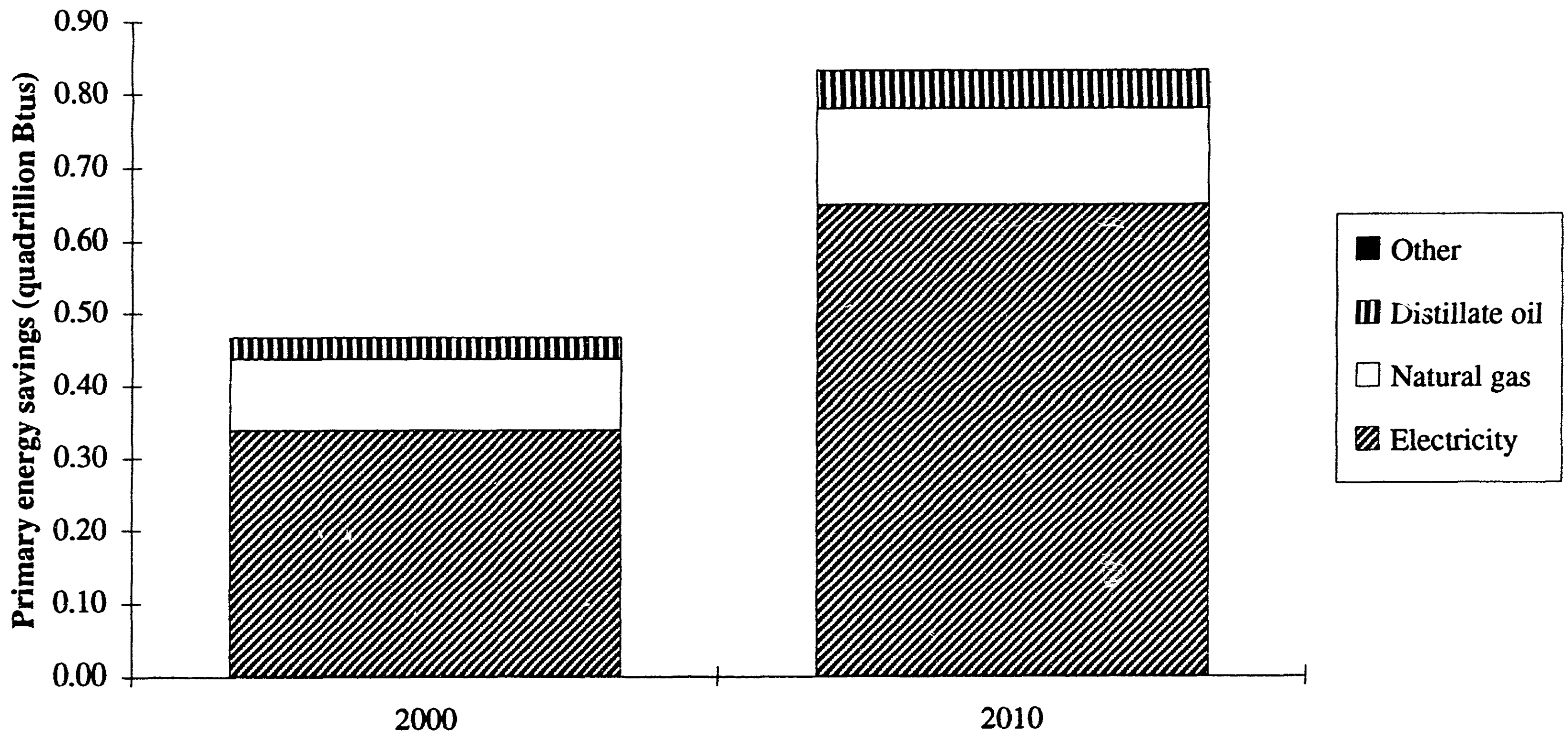


Figure 4: Primary energy savings from appliance standards



options can include advanced technology and for some end-uses in LBL REM, it does. However, in LBL REM as currently implemented, this menu of options and the characteristics of each technology on the menu remain fixed throughout the analysis period. In general, we expect that technological change over four decades will result in lower costs for currently existing efficiency options, and will create new options that save more energy than any existing or prototype technologies. These expected effects on the menu of technology options are not accounted for in the LBL REM forecasts.

Figure 5 shows the main result of assuming static menus of technology options. This Figure compares projected demand growth in the reference case (with appliance standards) with a case where the market discount rate used by LBL REM is reduced to 7% real, as well as with the 7% real case with $100/tonne carbon taxes. By sometime soon after 2010, electricity demand growth in the Reference Case becomes quite similar to that in the 7% Market Discount Rate Case. Even the addition of carbon taxes in the case with the highest carbon intensity (the NES Current Policy Base) fails to change this result substantially.

This Figure confirms that any residential-sector modeling methodology that fails to account for technological change cannot be relied on for policy impact analyses beyond about a 20 year time frame. This time period corresponds to the maximum lifetimes for most residential appliances and equipment (20-25 years).

IV. CONCLUSIONS

Our analysis leads to the following conclusions:

1) Total residential sector primary energy use and carbon emissions will remain roughly constant over the 1990-2000 period.

2) Residential *electricity* demand will grow at 1.2%/year over the 1990-2000 period. Electrical end uses growing faster than this average over the 1990-2000 period include electric resistance and heat pump heating, heat pump cooling, cooking, and miscellaneous.

3) In absolute terms (quadrillion BTUs of primary energy), the largest projected contributors to residential electricity demand growth over the 1990-2000 period are electric resistance and heat pump heating, water heating, cooking, lighting, and miscellaneous.

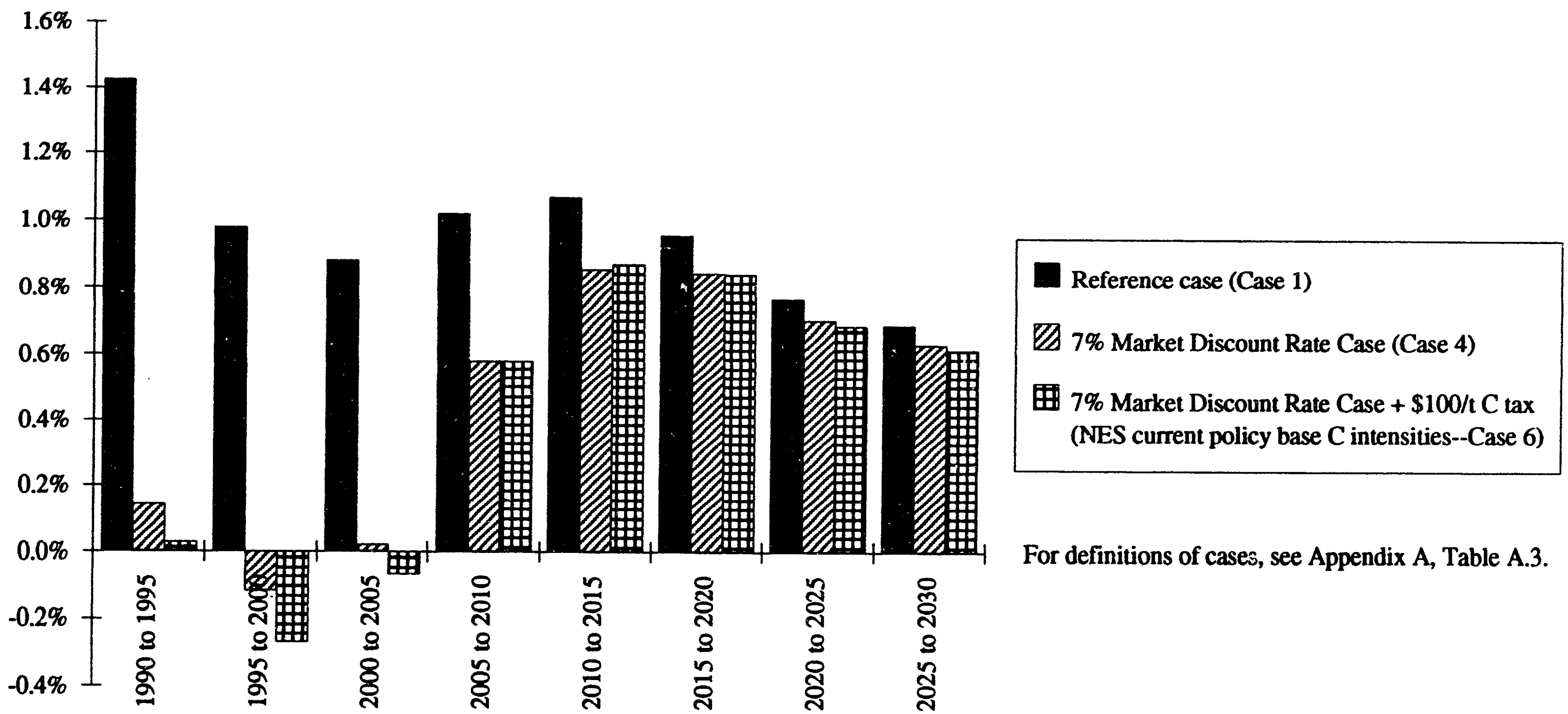
4) Total electricity use associated with residential refrigerator/freezers and freezers will decline at 2% to 5% per year from 1990-2000, in large part because of the 1993 efficiency standards on these products.

5) Appliance efficiency standards now in place for many end-uses will reduce residential primary energy use by 0.5 quads (2.7%) in 2000 and 0.8 quads (4.5%) in 2010 compared to a business-as-usual case without the standards.

6) Any residential-sector modeling methodology that fails to account for technological change is ill-suited for policy impact analyses that extend beyond about a 20-year time frame.

We are now creating detailed input data for the Electric Power Research Institute's REEPS forecasting framework, with the ultimate goal of replacing LBL REM for policy analysis purposes (Hwang et al. 1993, Johnson et al. 1993). This new tool combines great flexibility with a user-friendly interface.

Figure 5: Annual average growth rates in electricity demand for the U.S. residential sector



For definitions of cases, see Appendix A, Table A.3.

REFERENCES

Brown, Richard E. 1993. *Estimates of the Achievable Potential for Electricity Efficiency in U.S. Residences*. M.S. Thesis, Energy and Resources Group, University of California, Berkeley.

Carlsmith, Roger S., Chandler William U., James E. McMahon and Danilo J. Santini. 1990. *Energy Efficiency: How Far Can We Go*? Oak Ridge National Laboratory. ORNL/TM-11441. January.

CEC. 1990. *1988 Inventory of California Greenhouse Gas Emissions*. California Energy Commission. Preliminary Staff Report--DRAFT. May.

EPRI, Electric Power Research Institute. 1986. *TAG-Technical Assessment Guide: Vol. 1: Electricity Supply-1986*. EPRI. EPRI P-4463-SR. December.

EPRI, Electric Power Research Institute. 1989. *TAG-Technical Assessment Guide: Vol. 1: Electricity Supply-1989*. EPRI. EPRI P-6587-L. September.

Garver, L.L. 1966. "Effective Load Carrying Capability of Generating Units." *IEEE Transactions on Power Apparatus and Systems*. vol. 85, no. 8. p. 910.

Hwang, Roland J., Francis X. Johnson, James W. Hanford, Jonathan G. Koomey and Richard E. Brown. 1993. *Appliance data, assumptions and methodology for residential end-use forecasting with EPRI-REEPS 2.1*. Lawrence Berkeley Laboratory. DRAFT LBL-34046. June.

Johnson, Francis X., James W. Hanford, Alan H. Sanstad and Jonathan G. Koomey. 1993. *HVAC data, assumptions and methodology for residential end-use forecasting with EPRI-REEPS 2.1*. Lawrence Berkeley Laboratory. DRAFT LBL-34045. June.

Koomey, Jonathan, Celina Atkinson, Alan Meier, James E. McMahon, Stan Boghosian, Barbara Atkinson, Isaac Turiel, Mark D. Levine, Bruce Nordman and Peter Chan. 1991. *The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector*. Lawrence Berkeley Laboratory. LBL-30477. July.

Krause, Florentin, John F. Busch and Jonathan G. Koomey. 1992. *Incorporating Global Warming Risks in Power Sector Planning: A Case Study of the New England Region*. Lawrence Berkeley Laboratory. LBL-30797 (vols I and II). November.

Levine, Mark D. , Jon Koomey, Henry Ruderman, Paul Craig, James E. McMahon and Peter Chan. 1985. "Chapter 16: Economics of Efficiency Improvements in Residential Appliances and Space Conditioning Equipment." In *Energy Sources: Conservation and Renewables, Conference Proceedings #135*. Edited by D. Hafemeister. New York, NY: American Institute of Physics.

McMahon, James E. , Peter Chan, Joseph Eto, Jon Koomey, Mark Levine, Chris Pignone and Henry Ruderman. 1987. "The LBL Residential Energy and Hourly Demand Models." In *Strategic Planning in Energy and Resources*. Edited by B. e. a. Lev. Holland: Elsevier Science Publishers B.V.

Ruderman, Henry, Mark D. Levine and James E. McMahon. 1987. "The Behavior of the Market for Energy Efficiency in Residential Appliances Including Heating and Cooling Equipment." *The Energy Journal*. vol. 8, no. 1. p. 101.

US DOE, U.S. Department of Energy. 1988. *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators, Furnaces, and Television Sets*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0239. November.

US DOE, U.S. Department of Energy. 1989a. *Technical Support Document: Energy Conservation Standards for Consumer Products: Refrigerators and Furnaces*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0277. November.

US DOE, U.S. Department of Energy. 1989b. *Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0267. July.

US DOE, U.S. Department of Energy. 1990. *Technical Support Document: Energy Conservation Standards for Consumer Products: Dishwashers, Clothes Washers, and Clothes Dryers*. U.S. Department of Energy, Assistant Secretary, Conservation and Renewable Energy, Building Equipment Division. DOE/CE-0299P. December.

US DOE, U.S. Department of Energy. 1991a. *Annual Energy Outlook, with Projections to 2010*. Energy Information Administration. DOE/EIA-0383(91). March.

US DOE, U.S. Department of Energy. 1991b. *Electricity Supply: Supporting Analysis for the National Energy Strategy*. SR/NES/90-03. January.

US DOE, U.S. Department of Energy. 1991/1992. *Technical Annex 2: Integrated Analysis Supporting The National Energy Strategy: Methodology, Assumptions, and Results*. DOE/S-0086P.

US EPA. 1990. *Policy Options for Stabilizing Global Climate: Report to Congress, Main Report*. U.S. Environmental Protection Agency. 21P-2003.1. December.

Wood, David J., Henry Ruderman and James E. McMahon. 1989a. *Market Share Elasticities for Fuel and Technology Choice in Home Heating and Cooling*. Lawrence Berkeley Laboratory. LBL-20090. May.

Wood, David J., Henry Ruderman and James E. McMahon. 1989b. *A Review of Assumptions and Analysis in EPRI EA-3409, "Household Appliance Choice: Revision of REEPS Behavioral Models"*. Lawrence Berkeley Laboratory. LBL-20332. May.

Wood, David J., Henry Ruderman and James E. McMahon. 1989c. *A Study of Aggregation Bias in Estimating the Market for Home Heating and Cooling Equipment*. Lawrence Berkeley Laboratory. LBL-20333. May.

APPENDIX A: DETAILED PRESENTATION OF ASSUMPTIONS AND RESULTS

A.1: LBL REM MARKET EFFICIENCY CHOICES

For each end-use, LBL REM contains a relationship between consumer equipment price and energy use per appliance per year. These cost-efficiency relationships are derived from engineering data and from surveys of appliance manufacturers.[1]

The calculation of life-cycle costs requires a discount rate and a lifetime of the appliance.[2] In engineering calculations, the discount rate is usually chosen to reflect the cost of capital to the appliance purchaser (say 3 to 7% real). This discount rate plus the lifetime of the appliance can be used to calculate an annualized capital cost (Levine et al. 1985).

The annualized life-cycle cost of an appliance is defined as the annual operating costs plus the annualized capital costs. The curves of equipment price versus annual energy use can be converted to curves of life-cycle cost versus annual energy use by annualizing the equipment price and adding the annual operating expenses. The minimum life-cycle cost point on such curves defines the most cost-effective combination of capital and operating costs, given fuel prices and other assumptions.

Consumers often purchase appliances that are far from the minimum life-cycle cost point in terms of energy use (if life-cycle costs are calculated using discount rates similar to the cost of capital). When consumers exhibit such behavior, we can apply the concept of LCC minimization to "work backwards": given the average energy use of appliances that consumers purchase, we can calculate the "market discount rate" that results in a minimum life-cycle cost for the capital costs embodied in the appliance-cost-versus-energy-use curves. The market discount rate is an *empirical parameter* that characterizes the total of all factors affecting the efficiency of energy use, including cognitive biases, manufacturer behavior, retailer behavior, transactions costs, and other costs that are usually not included in the engineering calculations upon which assessments of conservation potential are often based.

Market discount rates are calculated using the method just described, and then applied throughout the analysis period to calculate life-cycle costs. The market is assumed to minimize life-cycle costs *using the market discount rate*. This method does not imply that any single consumer actually uses the market discount rates, but that the use of this discount rate with our cost-efficiency curves will yield an approximate characterization of the way the market for efficiency actually behaves at the margin. Previous analysis indicates that market discount rates, as defined in this fashion, have been fairly constant over time (Ruderman et al. 1987).

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[1] The markups needed to estimate consumer price from the engineering-based manufacturer costs are calculated using a model of manufacturer behavior developed by LBL for the appliance efficiency standards analysis (US DOE 1990).

[2] In the formulation of life-cycle costs described here, the discount rate and device lifetime are used to annualize the capital costs of the appliance. Alternatively, the discount rate can be applied to the projected annual operating costs of the appliance to present-value those costs and allow them to be added to the capital costs. Both formulations may be referred to as "life-cycle costing" and are functionally equivalent, but the first method is more commonly used.

A.2: INPUT DATA

Macroeconomic and fuel price assumptions

Table A.1 shows the exogenous input assumptions in the Reference case. The total number of households are taken from the National Energy Strategy's (NES's) Technical Annex 2, and are projected to increase more than 40% over the 40-year analysis period. Median household income is calculated by taking total personal income from the Annual Energy Outlook (US DOE 1991a), extrapolating it to 2030 using 2000 to 2010 growth rates, and dividing this total income by the number of households from the NES Technical Annex 2. Household income is expected to grow 54% in real terms from 1990 to 2030. Reference case fuel prices are taken from the National Energy Strategy's Technical Annex (US DOE 1991/1992). Natural gas prices are projected to show 1.9%/year growth in real terms, the largest rate of increase for any fuel included in this analysis. Real natural gas prices more than double over this period. Distillate oil and LPG prices show real increases averaging 1.2% per year and 1.0% per year respectively, while real electricity prices grow only at 0.3% per year over the analysis period.

The fuel prices without carbon taxes in the NES excursion are assumed to be the same as in the NES Current Policy Base. As **Table A.2** shows, this assumption introduces only a minor error into the results. It also greatly reduces the number of modeling runs, which is why we adopted this convention.

Policy cases

Table A.3 summarizes the policy cases that we analyze. These cases vary in their electricity supply mix, size of carbon tax, and demand-side case. This set of cases (24 in all) captures a wide range of plausible assumptions about the future.

Electricity supply mixes

As shown in **Table A.4**, carbon taxes on electricity are calculated using three different electricity supply mixes, for two levels of carbon taxes ($25/tonne[3] of carbon, and $100/tonne of carbon). Carbon taxes are assumed to be levied on consumers of electricity and fuels (as opposed to levying them on producers who may choose to absorb some of the tax for competitive reasons). These carbon taxes plus the baseline fuel prices from Table A.1 are used in the relevant policy cases.

Carbon emissions factors, calculated as shown in **Table A.5**, are derived from CEC (1990) using the National Energy Strategy's (NES) "Current Policy Base" and "NES Excursion" electricity fuel mixes, and an illustrative case where coal plants are replaced by a Generic Non-Fossil Resource (we refer to these cases as Supply Side Cases I, II, and III, respectively). This generic resource is assumed to cost the same amount per kWh as the coal plants it displaces (or in other cases to cost the same per kWh as the coal plants plus the $100/tonne carbon tax). These three cases span the likely range of possible carbon intensities for electricity generation.

We use the electricity carbon intensities (lbs/kWh.e) from Supply Side Cases I to III to calculate carbon emissions from residential electricity consumption. We assume that if

[3]All tonnes are metric tonnes, defined as 2200 lbs or 1000 kg. All dollar figures are in 1990 U.S. dollars.

electricity demand is reduced by policies, electric generation resources are deferred in exact proportion to their fraction of electric generation in the case where demand is unaffected by the policies. In principle, more or less carbon intensive resources could be deferred if demand-side policies reduced demand (depending on the load shape characteristics of the conservation and the operating characteristics of the supply resources), thereby changing the electricity carbon burden. For simplicity, we do not account for this second-order effect here.

In the case where the electricity carbon burden is reduced 50% relative to 1990 levels (Supply Side Case III), we also adjust the electricity price to reflect variations in the cost of the generic resource that replaces coal. We define the cost of the generic resource to be equal to that of coal (in which case no change in price is necessary) or equal to the cost of coal plus a $100/tonne carbon tax (which, as **Figure B.1** from Appendix B shows, is the same as adding 2¢/kWh or about 25% to the cost of coal plants or to the generic non-fossil resource). This parametric variation allows us to investigate the effect of a change in resource cost without defining the exact character of the generic resource.

We do not take a position on whether Supply Side Case III is desirable, because we have not undertaken the detailed national supply side analysis that would be required for such an assessment.[4] The approach we adopt in this analysis shows what would happen *if such changes on the supply side were implemented.* It is important to include this case here to demonstrate that the demand-side effect of carbon taxes can be reduced substantially if the carbon intensity of the electricity supply mix changes over the analysis period.

Carbon taxes

Figure A.1 shows the carbon tax associated with electricity consumption as a function of Supply-Side case and time (for the $100/tonne carbon tax). The increasing carbon intensity of electricity generation in the NES Current Policy Base (Supply-Side Case I) is reflected in the carbon tax increasing from 2¢/kWh.e in 1990 to 2.5¢/kWh.e in 2030. In the NES Scenario mix (Supply-Side Case II) the carbon burden does not change from 1990 to 2010, but declines slightly by 2030, resulting in a reduced carbon tax of 1.75¢/kWh.e. Supply-Side Case III reduces the carbon burden and the carbon tax to 1¢/kWh.e by 2030. This figure demonstrates that policies that result in a shift to non-fossil resources on the supply side (such as subsidies for particular technologies), could reduce the effectiveness of a carbon tax on the demand side.

Figure A.2 shows the percentage change in fuel prices due to the $100/tonne carbon tax in 1990 and 2030, for fuels and electricity. This Figure further reinforces the message of Figure A.1, with the additional complication that escalating fuel prices also reduce the relative (i.e. percentage) impact of carbon taxes over time.

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[4] See Krause et al (1992), for an analysis of the New England region that characterizes the low carbon resources necessary for regional power sector carbon intensity reductions of comparable or greater magnitude to those defined in Supply Side Case III.

Demand-side cases

We consider two demand cases[5]: the Reference Case and the 7% Market Discount Rate Case. Results for the Reference Case are calculated using base-case fuel prices and currently instituted appliance efficiency standards. The 7% Market Discount Rate Case is created by assuming that the *market discount rate* (discussed above) is reduced from the empirically-derived values in LBL REM (shown in **Table A.6**) to 7% real[6] , a discount rate that approximately characterizes the real discount rate for electric utility investment decisions. We do not specify the mechanisms by which the market discount rate may be reduced, only posit that it is reduced in some manner. This approach begs the question of energy savings that are *achievable* given real-world constraints, but it does allow an order-of-magnitude assessment of potential total energy savings, based on the engineering-economic data in LBL REM.

A.3: RESULTS

LBL REM produces a wealth of information, including energy use by fuel and end-use, average and new unit energy consumptions over time, average and new unit energy efficiency factors over time, and present values for expenditures on fuel and equipment over the analysis period. The inputs were varied as described above to calculate these outputs (not including the expenditures) for each of the 24 cases. The results are described below.

Total fuel use by end-use in the Reference Case

Table A.7 shows an end-use breakdown for Case 1 (which is identical in energy consumption to cases 7 and 13). Table A.7 reveals that the five largest end-uses in 1990 (in primary energy terms) are, in order of decreasing importance, natural gas space heating (central plus room), electric water heating, electric resistance space heating, oil space heating, and natural gas water heating. Together these four end-uses comprise about 8 quadrillion Btus of resource energy in 1990, or about half of total residential resource energy use.

The model predicts that electricity use and oil use will increase at about 1%/year in the Residential sector from 1990 to 2030, while natural gas and LPG will decline at 0.4% and 1.4%/yr, respectively. All categories of gas use except for gas dryers and gas miscellaneous decline in importance over this period (principally because of fuel switching to electricity). Refrigerator and freezer energy use will also decline substantially, because of the projected effects of the 1990 and 1993 appliance efficiency standards.

Table A.8 shows an end-use breakdown for the 7% Market Discount Rate Case (Case 4, which is identical in energy consumption to cases 10 and 16), and **Table A.9** compares the cumulative energy use by end-use for the Reference case (Case 1) and the 7% Market Discount Rate Case (Case 4). Changes in cumulative consumption shown in Table A.9 can be the result of efficiency improvements AND fuel switching, so care must be used in interpreting the results of these Tables. The biggest shifts in the 7% Market Discount Rate

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[5] As distinct from carbon taxes, which affect both the supply side and demand side.

[6]When a market discount rate is below 7% in the Reference Case (see Table A.6), we do not change its reference case value in the 7% Market Discount Rate Case.

Case occur in electric dryers and clothes washers. In the case of dryers, both fuel switching to gas dryers and efficiency improvements (principally caused by the adoption of heat pump dryers) cause cumulative electric dryer energy use in the 7% Market Discount Rate Case to be about one-third of the cumulative energy use in the Reference Case. For clothes washers, the reduction in cumulative energy use by a factor of two is caused by the shift to horizontal axis washing machines.[7]

Unit Energy Consumption

Tables A.10 and **A.11** show the unit energy consumption (UEC) for each end use in the Reference and 7% Market Discount Rate Cases, respectively. The UECs are measured in terms of resource energy using LBL REM's conversion factor of 11,500 Btus/kWh.e. They are a function of equipment efficiency (energy factor), fuel prices, equipment cost, and usage.

Energy factors

Tables A.12 and **A.13** show the energy factors (i.e. efficiencies) that correspond to the end-use breakdowns in Tables A.7 and A.8. These Tables indicate the extent of efficiency improvements in the Reference and 7% Market Discount Rate Cases. In particular, the efficiency improvements in electric dryers and clothes washers are quite substantial in the 7% Market Discount Rate case. However, the efficiency improvement for electric dryers is not sufficient to account for the changes in the total energy consumption of this appliance from the Reference to the 7% Market Discount Rate Cases, which confirms that both efficiency improvements and fuel switching must be responsible for those changes.

Saturations

Tables A.14 and **A.15** show the saturations for each end use in the Reference and 7% Market Discount Rate Cases, respectively. These saturations indicate the percentage of households in existing or new buildings that own a particular appliance using a particular fuel. The saturations are a function of personal income, relative fuel prices, equipment efficiencies, and equipment costs.

Total energy use by fuel and by case

Table A.16 shows total primary energy use by case and by fuel in 2030, **Table A.17** shows total primary energy use by case and by year, and **Table A.18** shows cumulative primary energy use by fuel. Electricity is the fuel most affected by the 7% Market Discount Rate Case, both in percentage terms and absolute terms. In all cases, electricity comprises around 70% of total primary energy, with gas at roughly 20%, and distillate oil and LPG comprising the rest. All cases show total primary energy consumption increasing over 1990 levels by 2030, though in the 7% Market Discount Rate Cases, total primary energy drops below 1990 levels in 2000 and 2010, and rises again after 2010. This effect is caused by our assumption of a static menu of technology options.

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[7] Horizontal axis washing machines are now available in top-loading versions, which eliminates any concerns that they deliver different levels of service than their vertical axis counterparts. Horizontal axis washing machines are quite common in Europe and in commercial washing establishments in the U.S., but are currently rare in U.S. homes.

Total carbon emissions

Table A.19 shows total carbon emissions by case and by fuel in 2030, and **Table A.20** shows total carbon emissions by case and by year. **Figures A.3** through **A.5** show the results for energy and carbon for key cases. The Reference Case demand implies substantial increases (roughly 50% over 1990 levels) in residential sector carbon emissions assuming NES Current Policy Base carbon intensities for electricity. In the NES Excursion, the Reference Case demand implies increases of 10 to 15% for total carbon emissions over 1990 levels, while for the supply side case where electricity carbon intensity is reduced to 50% of 1990 levels by 2030 (reference case demand), total residential carbon emissions are reduced by almost 20% compared to 1990 emissions.

The 7% Market Discount Rate cases with and without carbon taxes are also shown in Figures A.3 through A.5. This demand-side case reduces total carbon emissions by 15 to 20% relative to 2030 emissions in the reference case.

Revenues from carbon taxes

The results of the calculation of actual revenues from the carbon taxes are shown in **Table A.21**, as calculated using the carbon emissions from Table A.20. The 25$/tonne carbon tax yields revenues ranging from $4.5 billion 1990$ per year to $9 billion/year in 2030. The $100/tonne tax yields revenues of from $18 billion to $36 billion in 2030. If such taxes were applied to all sectors, the revenues would be considerably larger.

Effect of carbon taxes

Table A.22 shows the demand-side effect of carbon taxes on electricity use, gas use, and total primary energy use, as well as on the corresponding carbon emissions. This effect is expressed in this Table as a percentage change relative to the comparable case without carbon taxes. For example, with Reference Case demand and Supply-side case I (Current Policy Base carbon burdens), the $25/t carbon tax will reduce 2030 primary energy use by 1.4% compared to the same case without the carbon tax.

In general, carbon taxes of $100/t have four times the effect of $25/t taxes, but the relative effect can be from 3.6 to 4.6 times. The exact effect depends on the marginal cost of the next unit of efficiency improvement, as well as the market position of different fuels. The Table shows that fuel switching between electricity and gas affects the results. For Reference Case demand and the $100/t carbon tax, electricity demand in 2030 will be reduced by 6% in Supply Side Case I, while gas use will be reduced 5.3%. In Supply Side Case III, where electricity carbon burdens (and hence electricity prices with carbon taxes) have been reduced substantially, electricity use is reduced only 1.8%, while gas use is reduced by 7%. Carbon emissions by fuel scale linearly, but changes in total emissions are different than changes in total primary energy use because of the effect of fuel switching.

Table A.1: Input assumptions for residential policy analysis

	Units	1990	2000	2010	2020	2030	2030/1990	Average annual growth rate 1990-2030
Households								
Single family	millions	62.59	70.70	77.80	83.82	88.25	1.41	0.9%
Multifamily	millions	26.22	29.61	32.59	35.12	36.98	1.41	0.9%
Mobile home	millions	4.59	5.18	5.71	6.15	6.48	1.41	0.9%
Total	millions	93.40	105.50	116.10	125.10	131.70	1.41	0.9%
New households formed each year								
Single family	millions	1.191	1.177	1.150	0.989	0.988	0.83	-0.5%
Multifamily	millions	0.553	0.549	0.550	0.484	0.488	0.88	-0.3%
Mobile home	millions	0.174	0.185	0.192	0.188	0.194	1.11	0.3%
Total	millions	1.918	1.911	1.892	1.662	1.671	0.87	-0.3%
Median household income	10e3 1990$/household	42.09	44.75	50.37	57.07	64.65	1.54	1.1%
Current policy base site energy prices								
Electricity	1990¢/kWh	8.10	8.04	8.70	8.96	9.16	1.13	0.3%
Electricity	1990$/MMBtu	23.74	23.57	25.50	26.26	26.85	1.13	0.3%
Natural gas	1990$/MMBtu	5.69	8.04	9.74	11.21	12.22	2.15	1.9%
Distillate oil	1990$/MMBtu	7.64	8.87	10.72	11.78	12.52	1.64	1.2%
LPG	1990$/MMBtu	9.56	10.89	12.20	13.33	14.11	1.48	1.0%
Real discount rate	7%							

(1) Source of housing forecast: total households from NES Technical Annex 2 (US DOE 1991/1992), disaggregated into housetypes using ratios from a U.S. Census forecast (US Census 1983). New households derived from total households assuming annual retirement rates of 0.62% for single family, 0.82% for multifamily, and 2.5% for mobile homes.

(2) Source of fuel prices: National Energy Strategy current policy base from US DOE (1991/1992)

(3) Source of per capita income: U.S. DOE (1991a) for total income, divided by the total household forecast from US DOE (1991/1992), extrapolated to 2030 using 2000-2010 growth rates.

Table A.2: Comparison of NES current policy base and NES excursion site energy prices for the U.S. residential sector

	Units	*1990*	*2000*	*2010*	*2020*	*2030*	*2030/1990*	*Average annual growth rate 1990-2030*
NES current policy base								
Electricity	1990¢/kWh	8.10	8.04	8.70	8.96	9.16	1.13	0.3%
Electricity	1990$/MMBtu	23.74	23.57	25.50	26.26	26.85	1.13	0.3%
Natural gas	1990$/MMBtu	5.69	8.04	9.74	11.21	12.22	2.15	1.9%
Distillate oil	1990$/MMBtu	7.64	8.87	10.72	11.78	12.52	1.64	1.2%
LPG	1990$/MMBtu	9.56	10.89	12.20	13.33	14.11	1.48	1.0%
NES excursion								
Electricity	1990¢/kWh	8.10	8.39	8.82	9.04	9.13	1.13	0.3%
Electricity	1990$/MMBtu	23.74	24.59	25.85	26.49	26.75	1.13	0.3%
Natural gas	1990$/MMBtu	5.69	7.98	9.25	10.78	11.59	2.04	1.8%
Distillate oil	1990$/MMBtu	7.64	8.54	9.62	10.79	11.35	1.49	1.0%
LPG	1990$/MMBtu	9.56	11.10	12.08	13.25	13.88	1.45	0.9%
NES excursion/current policy base								
Electricity	Index	1.00	1.04	1.01	1.01	1.00		
Electricity	Index	1.00	1.04	1.01	1.01	1.00		
Natural gas	Index	1.00	0.99	0.95	0.96	0.95		
Distillate oil	Index	1.00	0.96	0.90	0.92	0.91		
LPG	Index	1.00	1.02	0.99	0.99	0.98		

(1) fuel prices from US DOE (1991/1992)

Table A.3: Key to residential model runs

Case #	Electricity Supply Mix (Carbon Intensity Scenario)	Carbon tax 1990$/tonne C	Generic Resource Cost	Demand Side Case	Relationship to other cases
0	NES Current Policy Base	0	n/a	no policies	unique
1	NES Current Policy Base	0	n/a	reference	unique
2	NES Current Policy Base	$25	n/a	reference	unique
3	NES Current Policy Base	$100	n/a	reference	unique
4	NES Current Policy Base	0	n/a	7% market discount rate	unique
5	NES Current Policy Base	$25	n/a	7% market discount rate	unique
6	NES Current Policy Base	$100	n/a	7% market discount rate	unique
7	NES Excursion	0	n/a	reference	Energy same as Case 1
8	NES Excursion	$25	n/a	reference	unique
9	NES Excursion	$100	n/a	reference	unique
10	NES Excursion	0	n/a	7% market discount rate	Energy same as Case 4
11	NES Excursion	$25	n/a	7% market discount rate	unique
12	NES Excursion	$100	n/a	7% market discount rate	unique
13	-50% from 1990	0	coal	reference	Energy same as Case 1
14	-50% from 1990	$25	coal	reference	unique
15	-50% from 1990	$100	coal	reference	unique
16	-50% from 1990	0	coal	7% market discount rate	Energy same as Case 4
17	-50% from 1990	$25	coal	7% market discount rate	unique
18	-50% from 1990	$100	coal	7% market discount rate	unique
19	-50% from 1990	0	coal+$100/t	reference	unique
20	-50% from 1990	$25	coal+$100/t	reference	unique
21	-50% from 1990	$100	coal+$100/t	reference	Energy same as Case 3
22	-50% from 1990	0	coal+$100/t	7% market discount rate	unique
23	-50% from 1990	$25	coal+$100/t	7% market discount rate	unique
24	-50% from 1990	$100	coal+$100/t	7% market discount rate	Energy same as Case 6

(1) NES current policy base assumes the electricity carbon intensity (g/kWh.e) implied in the National Energy Strategy's "No policy" case. The NES excursion assumes the electricity carbon intensity implied in the National Energy Strategy's "policy" case. "-50% from 1990" means that the electricity carbon intensity is reduced to 50% of 1990 levels by 2030, by substituting a generic non-fossil resource for coal-fired generation (see text for details). Carbon burdens for the direct use of gas, oil, and LPG remain constant throughout the analysis. g/kWh.e = grams per kWh of delivered electricity, including T&D losses.

(2) Carbon taxes are in 1990 $/metric tonne of carbon.

(3) Generic resource costs are only applicable in the "-50% from 1990" carbon burden case. This parameter tests the sensitivity of the analysis results to substituting higher cost resources for coal-fired resources in the electricity sector. The cost of the generic resource is assumed in this case to be the same as the cost of coal plants plus a $100/tonne carbon tax.

(4) The demand-side reference case includes the effects of fuel prices and the appliance efficiency standards currently "on the books". Case 0 is equal to Case 1 without appliance standards. The "7% market discount rate" case assumes that the empirically-derived "market discount rates" used for the reference case (which are often much higher than 7% real) are reduced to 7% real. The appliance standards are kept in place just as for the reference case. See text for details.

(5) As described in the text, supply-side (SS) Case 1 corresponds to NES Current Policy Base. SS Case 2 corresponds to the NES excursion. SS case 3 corresponds to a reduction in carbon intensity of electricity generation of 50% from 1990 levels by 2030.

Table A.4: Summary of carbon burdens and implied carbon taxes for fuels and electricity

Fuels	*Units*	*Natural gas*	*Distillate oil*	*Other residential*	*Utility residual oil*	*Utility coal*
Carbon burdens	lbs C/MMBtu	32.3	43.7	32.3	46.4	57.6
	g C/kWh.f	50.1	67.8	50.1	72.0	89.3
Carbon tax						
25$/tonne C	1990$/MMBtu	0.37	0.50	0.37	0.53	0.65
100$/tonne C	1990$/MMBtu	1.47	1.99	1.47	2.11	2.62
25$/tonne C	1990¢/kWh.f	0.13	0.17	0.13	0.18	0.22
100$/tonne C	1990¢/kWh.f	0.50	0.68	0.50	0.72	0.89

Electricity	*Units*	*NES current policy base*	*NES excursion*	*50% C burden reduction from 1990 levels*
Carbon burdens including T&D losses				
1990	g C/kWh.e	182	182	182
2000	g C/kWh.e	184	178	124
2010	g C/kWh.e	197	184	102
2020	g C/kWh.e	211	172	94
2030	g C/kWh.e	225	154	91
$25/tonne C Tax				
1990	1990¢/kWh.e	0.46	0.46	0.46
2000	1990¢/kWh.e	0.46	0.45	0.31
2010	1990¢/kWh.e	0.49	0.46	0.25
2020	1990¢/kWh.e	0.53	0.43	0.24
2030	1990¢/kWh.e	0.56	0.39	0.23
$100/tonne C Tax				
1990	1990¢/kWh.e	1.82	1.82	1.82
2000	1990¢/kWh.e	1.84	1.78	1.24
2010	1990¢/kWh.e	1.97	1.84	1.02
2020	1990¢/kWh.e	2.11	1.72	0.94
2030	1990¢/kWh.e	2.25	1.54	0.91

(1) fuel carbon burdens are taken from CEC 1990, and represent the direct emissions from burning the fuel. No indirect emissions from extraction, transport, or processing of the fuels are included. Direct emissions from nuclear, hydro, wind, and other renewables are assumed to be zero

(2) g C/kWh.f = grams of carbon emissions per kWh of fuel. g C/kWh.e= grams of carbon emissions per kWh of delivered final electricity (including the NES assumption of 7.5% transmission and distribution losses).

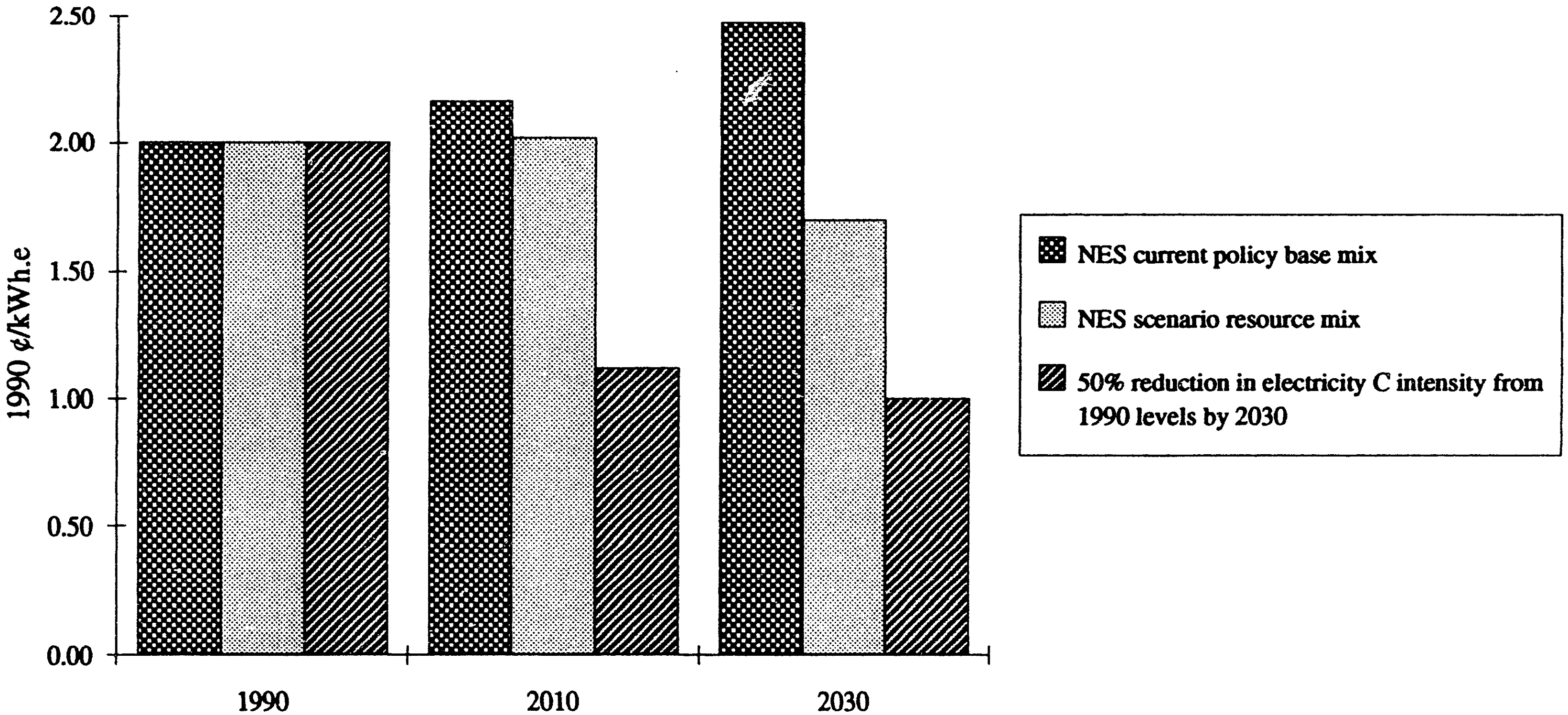
(3) other residential fuels' (e.g. LPG's) emissions are assumed to be the same as natural gas.

Table A.5: Total U.S. Electricity Generation and Carbon Emissions by Resource and Supply-Side Scenario 1990-2030

Resource	*Heat rate kWh.f/kWh.e*	*C burden of fuel g C/KWh.f*	*C burden w/o T&D losses g/kWh.e*	*NES current policy base mix 1990 TWh.e*	*2010 TWh.e*	*2030 TWh.e*	*NES excursion resource mix 1990 TWh.e*	*2010 TWh.e*	*2030 TWh.e*	*Electricity C burden -50% from 1990 mix 1990 TWh.e*	*2010 TWh.e*	*2030 TWh.e*
OIL steam	2.87	72.0	207	122	152	63	122	100	51	122	152	63
OIL combus. turbine	3.96	67.8	268	3	22	30	3	10	14	3	22	30
GAS steam	2.87	50.1	144	251	307	117	251	318	154	251	307	117
GAS combined cycle	2.22	50.1	111	107	206	98	107	162	89	107	206	98
GAS STIG/ISTIG	2.13	50.1	107	0	116	168	0	43	133	0	116	168
GAS combus. turbine	3.96	50.1	198	5	27	36	5	33	42	5	27	36
GAS fuel cell	1.89	50.1	95	0	7	18	0	3	11	0	7	18
GAS other turbines	3.03	50.1	152	0	3	15	0	1	10	0	3	15
COAL pulverized	3.03	89.3	271	1592	2107	1681	1592	1945	1346	1592	539	0
COAL AFB	2.86	89.3	255	0	322	1550	0	145	426	0	322	95
COAL PFB	2.46	89.3	220	0	143	1297	0	55	427	0	143	1297
COAL IGCC	2.70	89.3	241	0	295	720	0	208	432	0	295	720
COAL ISTIG	2.50	89.3	223	0	0	0	0	24	360	0	0	0
Total Nuclear	0	0	0	575	594	35	575	650	1195	575	594	35
Total Renewables	0	0	0	333	497	805	334	578	1037	333	497	805
Generic Non-fossil added	--	0	0	0	0	0	0	0	0	0	1568	3136
TOTAL (TWh.e)				2988	4798	6633	2989	4275	5727	2988	4798	6633
Average Carbon Burden (g C./KWh.e) w/o 7.5% T&D losses				*169*	*183*	*209*	*169*	*171*	*144*	*169*	*95*	*85*
Average Carbon Burden (g C./KWh.e) w/7.5% T&D losses				*182*	*197*	*225*	*182*	*184*	*154*	*182*	*102*	*91*
Index (1990 = 1.0)				1.00	1.08	1.24	1.00	1.01	0.85	1.00	0.56	0.50

(1) actual resource mixes used to calculate carbon taxes in Table A.4 were calculated for ten-year increments.
Twenty-year increments are shown here for convenience.
(2) NES Current Policy Base and NES Excursion are taken from DOE (1991/1992).
(3) Electricity carbon intensity -50% from 1990 levels case is adopted from NES Current Policy Base case, with the coal resources in this case replaced by sufficient "generic non-fossil resources" to reduce the carbon intensity to the appropriate level by 2030.
(4) The NES excursion includes some efficiency improvements (represented by the 900 TWh difference between the Current policy base mix and the NES excursion mix). Our analysis uses only the emissions factors per kWh and does not rely on total generation from NES.

Figure A.1: Size of electricity carbon tax as a function of electricity supply mix and year (tax = $100 per tonne of carbon)



Costs are in 1990 ¢/kWh of delivered electricity, including 7.5% T&D losses.

Figure A.2: Percentage changes in electricity and fuel prices due to taxes of $100 per tonne of carbon

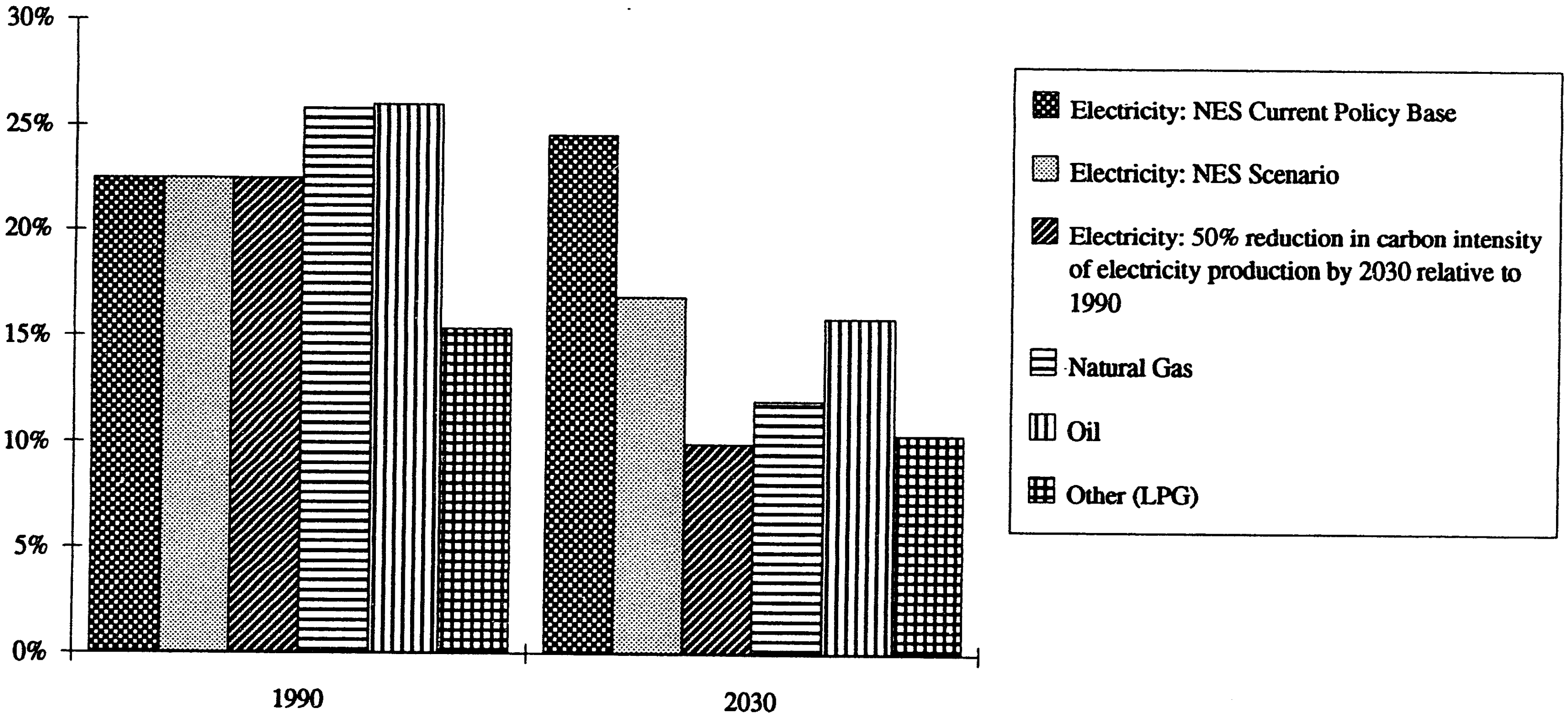


Table A.6: Market discount rates from LBL REM in Reference Case (Case 1)

Products using 2 parameter cost-efficiency curves	<---------- Replacement Unit--------->			<----------- New Unit ----------->		
	SF	MF	MH	SF	MF	MH
Central Gas Furnace	30%	13%	17%	25%	11%	13%
Central Oil Furnace	35%	41%	21%	29%	33%	14%
Room Gas Furnace	148%	124%	117%	126%	110%	87%
Room Oil Furnace	332%	488%	261%	332%	386%	168%
Room A/C	22%	5%	11%	21%	5%	10%
Central A/C	16%	0%	5%	16%	-1%	4%
Heat Pump	16%	2%	7%	17%	1%	6%
Electric Water Heat	196%	150%	165%	196%	150%	165%
Gas Water Heat	63%	48%	52%	63%	48%	52%
Oil Water Heat	79%	60%	66%	79%	60%	66%
Electric Cooking	35%	35%	34%	35%	35%	34%
Gas Cooking	-3%	-3%	-4%	-3%	-3%	-4%
Electric Miscellaneous	13%	13%	13%	13%	13%	13%
Gas Miscellaneous	48%	48%	48%	48%	48%	48%

Products using discrete design options

Refrigerator		*Freezer*	
SD-M (Manual Defrost)	78%	UP-M (Upright Manual)	108%
TF-P (Partial Auto Defrost)	120%	UP-A (Upright Auto Defrost)	122%
TF-A (Top Mount A/D w/o ttd)	219%	CH-M (Chest Manual Defrost)	211%
TFAI (Top Mount A/D with ttd)	259%		
BF-A (Bottom Mount Auto Defr)	256%	*Electric Dryer*	
SS-A (Side-by-Side w/o ttd)	263%	Std (Standard)	80%
SSAI (Side-by-Side with ttd)	279%	120V (Compact 120V)	33%
		240V (Compact 240V)	36%
Dishwasher			
Standard Dishwashers	99%	*Gas Dryer*	26%
Standard Water Heating DW	86%		
Compact Dishwashers 115V	59%		
Clothes Washer			
Standard	216%		
Compact	140%		

(1) Market discount rates are calculated empirically by assuming that the market's choice for appliance purchases in a given year is the minimum life-cycle cost point, and estimating the discount rate that would have to be used with the engineering-based cost-efficiency curves to choose the efficiency that the market actually chose in that year. Ruderman et al. 1987 showed that this parameter is relatively constant over time.

(2) Products using two-parameter cost-efficiency curves use the functional form described in Ruderman et al. 1987.

(3) Products using discrete design options are those that have been more recently analyzed (see US DOE 1988, US DOE 1989a, US DOE 1989b, US DOE 1990). The cost-efficiency curves for other appliances will be put into the discrete form as ongoing appliance efficiency standards analyses are completed.

Table A.7: Reference case (Case 1) forecast of residential energy use by end-use and fuel (Quadrillion Btus of resource energy)

End-use	Fuel	1990	2000	2010	2020	2030	2030/1990	Average annual growth rate
Total fuel use	Electricity	9.83	11.08	12.18	13.47	14.48	1.47	1.0%
	Natural gas	4.84	4.21	4.12	4.07	4.10	0.85	-0.4%
	Oil	1.13	1.11	1.25	1.51	1.68	1.49	1.0%
	Other/LPG	0.17	0.15	0.14	0.13	0.11	0.63	-1.1%
	Total	*15.97*	*16.54*	*17.70*	*19.17*	*20.37*	*1.28*	*0.6%*
Central heat	Electricity	0.817	1.197	1.417	1.613	1.724	2.11	1.9%
	Natural gas	2.659	2.378	2.364	2.355	2.394	0.90	-0.3%
	Oil	1.029	1.034	1.173	1.420	1.594	1.55	1.1%
	Other	0.381	0.267	0.225	0.203	0.175	0.46	-1.9%
	HP	0.465	0.674	0.754	0.795	0.813	1.75	1.4%
	Total	*5.351*	*5.550*	*5.933*	*6.386*	*6.700*	*1.25*	*0.6%*
Room heat	Electricity	0.464	0.612	0.646	0.687	0.706	1.52	1.1%
	Natural gas	0.569	0.457	0.432	0.404	0.389	0.68	-0.9%
	Oil	0.036	0.039	0.042	0.045	0.046	1.28	0.6%
	Other/LPG	0.064	0.061	0.059	0.052	0.044	0.69	-0.9%
	Total	*1.133*	*1.169*	*1.179*	*1.188*	*1.185*	*1.05*	*0.1%*
Air conditioning	Room	0.317	0.338	0.385	0.446	0.501	1.58	1.2%
	Central	0.682	0.744	0.881	1.036	1.182	1.73	1.4%
	HP	0.200	0.252	0.284	0.307	0.321	1.61	1.2%
	Total	*1.199*	*1.334*	*1.550*	*1.789*	*2.004*	*1.67*	*1.3%*
Water heat	Electricity	1.691	1.883	2.112	2.324	2.464	1.46	0.9%
	Natural gas	0.900	0.856	0.846	0.853	0.885	0.98	0.0%
	Oil	0.061	0.035	0.038	0.041	0.043	0.70	-0.9%
	Other/LPG	0.069	0.058	0.055	0.048	0.041	0.59	-1.3%
	Total	*2.721*	*2.832*	*3.051*	*3.266*	*3.433*	*1.26*	*0.6%*
Refrigerators	Electricity	*1.515*	*1.264*	*1.142*	*1.200*	*1.270*	*0.84*	*-0.4%*
Freezers	Electricity	*0.428*	*0.254*	*0.206*	*0.209*	*0.220*	*0.51*	*-1.6%*
Cooking	Electricity	0.711	0.877	0.980	1.075	1.143	1.61	1.2%
	Natural gas	0.198	0.106	0.104	0.100	0.100	0.51	-1.7%
	Oil	0.001	0.001	0.001	0.001	0.001	1.00	0.0%
	Other/LPG	0.040	0.026	0.027	0.026	0.024	0.60	-1.3%
	Total	*0.950*	*1.010*	*1.112*	*1.202*	*1.268*	*1.33*	*0.7%*
Dryer	Electricity	0.524	0.588	0.642	0.711	0.775	1.48	1.0%
	Natural gas	0.050	0.054	0.058	0.061	0.063	1.26	0.6%
	Total	*0.574*	*0.642*	*0.700*	*0.772*	*0.838*	*1.46*	*1.0%*
Lighting	Electricity	*1.187*	*1.375*	*1.536*	*1.693*	*1.826*	*1.54*	*1.1%*
Miscellaneous	Electricity	0.658	0.838	0.994	1.153	1.291	1.96	1.7%
	Natural gas	0.084	0.091	0.094	0.095	0.098	1.17	0.4%
	Total	*0.742*	*0.929*	*1.088*	*1.248*	*1.389*	*1.87*	*1.6%*
Dishwasher	Electricity	*0.087*	*0.087*	*0.092*	*0.103*	*0.115*	*1.32*	*0.7%*
Clothes washer	Electricity	*0.086*	*0.096*	*0.106*	*0.116*	*0.124*	*1.44*	*0.9%*

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1.
(2) Electricity is measured in quadrillion Btus of resource energy, calculated using a conversion factor of 11,500 Btus/kWh.e. This factor includes transmission and distribution losses as well as losses associated with the generation of electricity
(3) Clothes washer and dishwasher energy is that associated with motors, and does not include the energy used to heat the water used by these appliances (which is counted under water heater energy use).
(4) "Other" under central heating means gas hydronic systems.

Table A.8: 7% Market Discount Rate case (Case 4) forecast of residential energy use by end-use and fuel (Quadrillion Btus of resource energy)

End-use	*Fuel*	*1990*	*2000*	*2010*	*2020*	*2030*	*2030/1990*	*Average annual growth rate*
Total fuel use	Electricity	9.81	10.18	10.65	11.66	12.50	1.27	0.6%
	Natural gas	4.84	3.90	3.72	3.69	3.76	0.78	-0.6%
	Oil	1.13	1.07	1.17	1.39	1.54	1.36	0.8%
	Other/LPG	0.17	0.12	0.11	0.10	0.09	0.50	-1.7%
	Total	*15.95*	*15.27*	*15.65*	*16.84*	*17.88*	*1.12*	*0.3%*
Central heat	Electricity	0.817	1.208	1.428	1.614	1.713	2.10	1.9%
	Natural gas	2.660	2.278	2.218	2.202	2.249	0.85	-0.4%
	Oil	1.030	1.006	1.115	1.325	1.473	1.43	0.9%
	Other	0.381	0.256	0.209	0.188	0.164	0.43	-2.1%
	HP	0.465	0.652	0.722	0.763	0.780	1.68	1.3%
	Total	*5.353*	*5.400*	*5.692*	*6.092*	*6.379*	*1.19*	*0.4%*
Room heat	Electricity	0.463	0.593	0.602	0.627	0.639	1.38	0.8%
	Natural gas	0.565	0.412	0.379	0.366	0.364	0.64	-1.1%
	Oil	0.036	0.033	0.032	0.033	0.035	0.97	-0.1%
	Other/LPG	0.063	0.054	0.049	0.043	0.036	0.57	-1.4%
	Total	*1.127*	*1.092*	*1.062*	*1.069*	*1.074*	*0.95*	*-0.1%*
Air conditioning	Room	0.317	0.322	0.356	0.408	0.456	1.44	0.9%
	Central	0.682	0.716	0.816	0.940	1.059	1.55	1.1%
	HP	0.200	0.230	0.248	0.265	0.275	1.38	0.8%
	Total	*1.199*	*1.268*	*1.420*	*1.613*	*1.790*	*1.49*	*1.0%*
Water heat	Electricity	1.690	1.616	1.671	1.808	1.912	1.13	0.3%
	Natural gas	0.900	0.669	0.599	0.620	0.656	0.73	-0.8%
	Oil	0.061	0.027	0.025	0.027	0.028	0.46	-1.9%
	Other/LPG	0.069	0.042	0.034	0.030	0.026	0.38	-2.4%
	Total	*2.720*	*2.354*	*2.329*	*2.485*	*2.622*	*0.96*	*-0.1%*
Refrigerators	Electricity	*1.515*	*1.154*	*0.961*	*1.004*	*1.062*	*0.70*	*-0.9%*
Freezers	Electricity	*0.428*	*0.222*	*0.152*	*0.154*	*0.163*	*0.38*	*-2.4%*
Cooking	Electricity	0.709	0.837	0.909	0.996	1.058	1.49	1.0%
	Natural gas	0.198	0.106	0.104	0.099	0.100	0.51	-1.7%
	Oil	0.001	0.001	0.001	0.001	0.001	1.00	0.0%
	Other/LPG	0.040	0.026	0.027	0.026	0.024	0.60	-1.3%
	Total	*0.948*	*0.970*	*1.041*	*1.122*	*1.183*	*1.25*	*0.6%*
Dryer	Electricity	0.505	0.280	0.138	0.117	0.135	0.27	-3.2%
	Natural gas	0.052	0.088	0.114	0.125	0.130	2.50	2.3%
	Total	*0.557*	*0.368*	*0.252*	*0.242*	*0.265*	*0.48*	*-1.8%*
Lighting	Electricity	*1.187*	*1.375*	*1.536*	*1.693*	*1.826*	*1.54*	*1.1%*
Miscellaneous	Electricity	0.657	0.829	0.975	1.124	1.252	1.91	1.6%
	Natural gas	0.084	0.091	0.094	0.094	0.096	1.14	0.3%
	Total	*0.741*	*0.920*	*1.069*	*1.218*	*1.348*	*1.82*	*1.5%*
Dishwasher	Electricity	*0.087*	*0.085*	*0.091*	*0.102*	*0.114*	*1.31*	*0.7%*
Clothes washer	Electricity	*0.084*	*0.057*	*0.045*	*0.049*	*0.053*	*0.63*	*-1.1%*

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1 and a 7% real discount rate for all consumer decisions regarding efficiency choice.

(2) Electricity is measured in quadrillion Btus of resource energy, calculated using a conversion factor of 11,500 Btus/kWh.e. This factor includes transmission and distribution losses as well as losses associated with the generation of electricity

(3) Clothes washer and dishwasher energy is that associated with motors, and does not include the energy used to heat the water used by these appliances (which is counted under water heater energy use).

(4) "Other" under central heating means gas hydronic systems.

Table A.9: Comparison of Reference Case (Case 1) cumulative energy use to 7% Market Discount Rate Case (Case 4) cumulative energy use (Quadrillion Btus of resource energy)

End-use	*Fuel*	*Reference case cumulative 1990-2030*	*7% Discount Rate Case cumulative 1990-2030*	*Ref. case/7% discount rate case cumulative 1990-2030*
Total fuel use	Electricity	611	540	0.88
	Natural gas	213	186	0.87
	Oil	73	68	0.93
	Other	7	17	2.54
	Total	*904*	*812*	*0.90*
Central heat	Electricity	76.2	76.2	1.00
	Natural gas	124.8	118.6	0.95
	Oil	69.1	65.1	0.94
	Other	11.8	11.2	0.95
	HP	34.2	33.2	0.97
	Total	*316.0*	*304.3*	*0.96*
Room heat	Electricity	34.0	31.6	0.93
	Natural gas	22.6	20.8	0.92
	Oil	2.3	1.8	0.78
	Other/LPG	2.8	2.4	0.86
	Total	*61.6*	*56.6*	*0.92*
Air conditioning	Room	19.7	18.3	0.93
	Central	43.6	40.3	0.92
	HP	13.2	11.7	0.88
	Total	*76.6*	*70.3*	*0.92*
Water heat	Electricity	101.9	82.8	0.81
	Natural gas	40.9	31.3	0.77
	Oil	1.9	1.4	0.72
	Other/LPG	2.4	1.7	0.70
	Total	*147.1*	*117.3*	*0.80*
Refrigerators	Electricity	*63.1*	*55.0*	*0.87*
Freezers	Electricity	*12.5*	*10.2*	*0.81*
Cooking	Electricity	49.7	46.5	0.94
	Natural gas	5.5	5.5	1.00
	Oil	0.0	0.0	1.00
	Other/LPG	1.3	1.3	1.00
	Total	*56.6*	*53.4*	*0.94*
Dryer	Electricity	34.1	9.9	0.29
	Natural gas	3.0	5.5	1.88
	Total	*37.1*	*15.4*	*0.42*
Lighting	Electricity	*64.4*	*64.4*	*1.00*
Miscellaneous	Electricity	54.2	52.9	0.98
	Natural gas	4.6	4.6	0.99
	Total	*58.8*	*57.5*	*0.98*
Dishwasher	Electricity	*4.8*	*4.7*	*0.99*
Clothes washer	Electricity	*5.3*	*2.7*	*0.50*

(1) Electricity is measured in quadrillion Btus of resource energy, calculated using a conversion factor of 11,500 Btus/kWh.e. This factor includes transmission and distribution losses as well as losses associated with the generation of electricity

(2) Clothes washer and dishwasher energy is that associated with motors, and does not include the energy used to heat the water used by these appliances (which is counted under water heater energy use).

(3) "Other" under central heating means gas hydronic systems.

Table A.10: Reference case (Case 1) forecast of residential equipment unit energy consumption by end-use, housing type, and equipment type (MMBtu/Unit)

	Housing: / Equipment:	*All Stock*	*All Stock*	*All New*	*All New*	*All Stock*	*All New*
End-Use	***Fuel***	*1990*	*2030*	*1990*	*2030*	*2030/1990*	*2030/1990*
Central heat	Electricity	119.8	120.2	107.5	107.4	*1.00*	*1.00*
	Natural gas	57.7	38.5	47.5	37.3	*0.67*	*0.79*
	Oil	88.0	72.2	83.5	73.8	*0.82*	*0.88*
	Other	62.9	42.8	51.5	41.1	*0.68*	*0.80*
	HP	67.5	66.6	65.9	66.5	*0.99*	*1.01*
Room heat	Electricity	96.3	96.9	77.0	74.1	*1.01*	*0.96*
	Natural gas	57.3	42.7	58.9	40.8	*0.75*	*0.69*
	Oil	64.2	56.1	61.8	54.9	*0.87*	*0.89*
	Other	64.7	54.9	63.6	49.9	*0.85*	*0.78*
Air conditioning	Room	8.0	7.1	6.7	7.2	*0.89*	*1.07*
	Central	27.9	25.7	24.9	25.9	*0.92*	*1.04*
	HP	28.7	26.4	25.1	26.5	*0.92*	*1.06*
Water heat	Electricity	44.3	39.7	40.7	39.7	*0.90*	*0.98*
	Natural gas	18.8	13.8	16.2	13.7	*0.74*	*0.84*
	Oil	22.3	19.1	19.9	18.5	*0.86*	*0.93*
	Other	19.9	15.6	19.6	15.9	*0.78*	*0.81*
Refrigerators	Electricity	14.1	8.2	10.7	8.1	*0.58*	*0.76*
Freezers	Electricity	12.7	5.4	6.8	5.4	*0.43*	*0.80*
Cooking	Electricity	11.7	11.1	10.9	11.1	*0.95*	*1.02*
	Natural gas	7.4	4.2	4.9	4.1	*0.57*	*0.84*
	Oil	11.3	11.0	11.3	11.0	*0.98*	*0.98*
	Other	7.0	5.0	5.3	4.9	*0.72*	*0.94*
Dryer	Electricity	10.4	9.3	10.1	9.3	*0.89*	*0.92*
	Natural gas	3.7	3.2	3.5	3.2	*0.87*	*0.92*
Lighting	Electricity	24.5	25.3	24.5	25.3	*1.03*	*1.03*
Miscellaneous	Electricity	16.5	17.0	16.5	17.0	*1.03*	*1.03*
	Natural gas	3.15	3.06	3.15	3.06	*0.97*	*0.97*
Dishwasher	Electricity	1.99	1.55	1.80	1.54	*0.78*	*0.86*
Clothes washer	Electricity	1.14	1.03	1.05	1.02	*0.90*	*0.97*

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1.
(2) Electricity is treated as resource energy using a conversion factor of 11,500 Btus/kWh.
(3) UECs for Dishwasher and Clothes washer include only motor energy. Energy to heat the water used in these appliances is counted under water heating.
(4) "Other" under central heating means gas hydronic systems.

Table A.11: 7% Market Discount Rate Case (Case 4) forecast of residential equipment unit energy consumption by end-use, housing type, and equipment type (MMBtu/Unit)

	Housing: *Equipment:*	*All* *Stock*	*All* *Stock*	*All* *New*	*All* *New*	*All* *Stock*	*All* *New*
End-Use	***Fuel***	*1990*	*2030*	*1990*	*2030*	*2030/1990*	*2030/1990*
Central heat	Electricity	119.9	122.6	107.5	109.4	*1.02*	*1.02*
	Natural gas	57.7	35.8	47.5	35.1	*0.62*	*0.74*
	Oil	88.1	68.3	83.5	69.6	*0.78*	*0.83*
	Other	62.9	39.3	51.5	38.1	*0.63*	*0.74*
	HP	67.5	63.8	65.9	65.8	*0.95*	*1.00*
Room heat	Electricity	96.3	99.2	77.1	75.8	*1.03*	*0.98*
	Natural gas	56.9	36.1	41.3	34.9	*0.64*	*0.84*
	Oil	63.8	46.8	47.7	45.6	*0.73*	*0.96*
	Other	64.4	44.0	44.3	41.0	*0.68*	*0.92*
Air conditioning	Room	8.0	6.4	6.7	6.5	*0.81*	*0.97*
	Central	27.9	22.9	24.9	23.0	*0.82*	*0.92*
	HP	28.7	22.7	25.1	22.5	*0.79*	*0.89*
Water heat	Electricity	44.3	32.0	38.0	31.9	*0.72*	*0.84*
	Natural gas	18.7	9.9	15.5	9.8	*0.53*	*0.63*
	Oil	22.3	13.3	18.7	12.9	*0.60*	*0.69*
	Other	19.9	9.8	18.7	10.0	*0.49*	*0.54*
Refrigerators	Electricity	14.1	6.8	10.7	6.8	*0.48*	*0.63*
Freezers	Electricity	12.7	4.1	6.8	4.0	*0.32*	*0.59*
Cooking	Electricity	11.6	10.3	10.0	10.2	*0.88*	*1.02*
	Natural gas	7.4	4.2	4.9	4.1	*0.57*	*0.84*
	Oil	11.3	11.0	11.3	11.0	*0.98*	*0.98*
	Other	7.0	5.0	5.3	4.9	*0.72*	*0.94*
Dryer	Electricity	10.3	3.6	3.4	3.4	*0.35*	*1.00*
	Natural gas	3.7	3.2	3.3	3.2	*0.87*	*0.98*
Lighting	Electricity	24.5	25.3	24.5	25.3	*1.03*	*1.03*
Miscellaneous	Electricity	16.4	16.5	16.2	16.3	*1.00*	*1.01*
	Natural gas	3.15	3.01	3.15	2.94	*0.96*	*0.93*
Dishwasher	Electricity	1.98	1.55	1.62	1.54	*0.78*	*0.95*
Clothes washer	Electricity	1.13	0.70	0.65	0.65	*0.62*	*1.00*

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1 and a 7% real discount rat for all consumer decisions regarding efficiency choice.

(2) Electricity is treated as resource energy using a conversion factor of 11,500 Btus/kWh.

(3) UECs for Dishwasher and Clothes washer include only motor energy. Energy to heat the water used in these appliances is counted under water heating.

(4) "Other" under central heating means gas hydronic systems.

Table A.12: Reference case (Case 1) forecast of residential energy factors by end-use and fuel

End Use	*Fuel*	*Units*	*Stock 1990*	*Stock 2030*	*New 1990*	*New 2030*	*Stock 2030/1990*	*New 2030/1990*
Central heat	Electricity	Efficiency	100	100	100	100	1.00	1.00
	Natural gas	AFUE	67.0	81.4	81.5	81.5	1.21	1.00
	Oil	AFUE	75.7	80.2	80.2	80.2	1.06	1.00
	Other	AFUE	66.2	81.6	81.5	81.9	1.23	1.01
	HP	HPSF	6.8	7.4	7.2	7.5	1.10	1.03
Room heat	Electricity	Efficiency	100	100	100	100	1.00	1.00
	Natural gas	AFUE	65.0	70.3	65.0	72.0	1.08	1.11
	Oil	AFUE	75.0	75.0	75.0	75.0	1.00	1.00
	Other	AFUE	65.0	65.0	65.0	65.0	1.00	1.00
Air conditioning	Room	EER	7.46	8.99	9.00	9.00	1.21	1.00
	Central	SEER	8.60	10.47	9.96	10.50	1.22	1.05
	HP	SEER	8.56	10.42	9.86	10.50	1.22	1.06
Water heat	Electricity	Efficiency	83.5	87.9	88.0	88.0	1.05	1.00
	Natural gas	Efficiency	50.7	64.2	56.1	65.1	1.27	1.16
	Oil	Efficiency	48.5	51.2	49.4	51.7	1.06	1.05
	Other	Efficiency	47.9	56.8	47.9	57.6	1.19	1.20
Refrigerators	Electricity	cu.ft./kWh-day	6.49	11.06	8.42	11.11	1.70	1.32
Freezers	Electricity	cu.ft./kWh-day	9.50	19.83	15.91	19.88	2.09	1.25
Dryer	Electricity	lb wet clothing/kWh	2.69	3.01	2.76	3.01	1.12	1.09
	Natural gas	lb wet clothing/kWh	2.32	2.66	2.46	2.67	1.15	1.09
Dishwasher	*Electricity*	loads/kWh	0.37	0.46	0.38	0.46	1.24	1.21
Clothes washer	*Electricity*	cu.ft./kWh	1.31	1.61	1.46	1.62	1.23	1.11

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1.

(2) Energy factors for cooking, lighting, and miscellaneous are not defined.

(3) Energy factors are based on U.S. government test procedures.

Table A.13: 7% Market Discount Rate Case (Case 4) forecast of residential energy factors by end-use and fuel

End Use	*Fuel*	*Units*	*Stock 1990*	*Stock 2030*	*New 1990*	*New 2030*	*Stock 2030/1990*	*New 2030/1990*
Central heat	Electricity	Efficiency	100	100	100	100	1.00	1.00
	Natural gas	AFUE	67.0	94.7	81.5	95.2	1.41	1.17
	Oil	AFUE	75.7	88.1	80.2	88.4	1.16	1.10
	Other	AFUE	66.2	94.3	81.5	94.9	1.43	1.16
	HP	HPSF	6.8	8.0	7.2	8.0	1.18	1.11
Room heat	Electricity	Efficiency	100	100	100	100	1.00	1.00
	Natural gas	AFUE	65.7	92.8	91.4	93.0	1.41	1.02
	Oil	AFUE	75.5	96.8	97.0	97.0	1.28	1.00
	Other	AFUE	65.5	93.0	92.8	93.3	1.42	1.00
Air conditioning	Room	EER	7.46	9.51	9.00	9.54	1.27	1.06
	Central	SEER	8.60	11.57	9.96	11.66	1.35	1.17
	HP	SEER	8.56	11.97	9.86	12.14	1.40	1.23
Water heat	Electricity	Efficiency	83.5	96.8	88.0	97.0	1.16	1.10
	Natural gas	Efficiency	50.7	78.0	56.1	78.5	1.54	1.40
	Oil	Efficiency	48.5	64.5	49.4	64.8	1.33	1.31
	Other	Efficiency	47.9	78.9	47.9	79.5	1.65	1.66
Refrigerators	Electricity	cu.ft./kWh-day	6.49	13.21	8.42	13.28	2.04	1.58
Freezers	Electricity	cu.ft./kWh-day	9.50	26.66	15.91	26.75	2.81	1.68
Dryer	Electricity	lb wet clothing/kWh	2.75	8.04	8.20	8.21	2.92	1.00
	Natural gas	lb wet clothing/kWh	2.33	2.66	2.61	2.67	1.14	1.02
Dishwasher	*Electricity*	loads/kWh	0.37	0.47	0.46	0.47	1.27	1.02
Clothes washer	*Electricity*	cu.ft./kWh	1.40	3.70	3.76	3.77	2.64	1.00

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1 and a 7% real discount rate for all consumer decisions regarding efficiency choice.
(2) Energy factors for cooking, lighting, and miscellaneous are not defined.
(3) Energy factors are based on U.S. government test procedures.

Table A.14: Reference case (Case 1) forecast of residential equipment saturations by end-use, housing type, and equipment type

	Housing:	*Existing*	*Existing*	*Existing*	*Existing*	*New*	*New*
	Equipment:	*Existing*	*Existing*	*New*	*New*	*New*	*New*
	Year:	*1990*	*2030*	*1990*	*2030*	*1990*	*2030*
Central heat	Electricity	8%	12%	6%	10%	16%	18%
	Natural gas	47%	44%	55%	49%	41%	39%
	Oil	12%	16%	19%	23%	2%	1%
	Other	6%	3%	6%	3%	2%	1%
	HP	8%	9%	14%	15%	28%	30%
	None	0%	0%	0%	0%	0%	0%
Room heat	Electricity	7%	7%	23%	36%	9%	10%
	Natural gas	11%	7%	67%	55%	1%	1%
	Oil	1%	1%	4%	5%	0%	0%
	Other	1%	1%	5%	3%	1%	1%
	None	0%	0%	2%	1%	0%	0%
Air conditioning	Room	29%	37%	39%	40%	10%	10%
	Central	26%	35%	31%	40%	43%	50%
	HP	8%	9%	5%	7%	28%	30%
	None	38%	20%	25%	13%	19%	10%
Water heat	Electricity	41%	47%	38%	44%	60%	64%
	Natural gas	51%	49%	57%	52%	36%	33%
	Oil	3%	2%	2%	2%	2%	2%
	Other	4%	2%	3%	2%	2%	1%
	None	1%	1%	1%	0%	0%	0%
Refrigerators	Electricity	115%	118%	117%	119%	114%	117%
	None	10%	7%	8%	6%	11%	8%
Freezers	Electricity	36%	31%	36%	37%	21%	20%
	None	64%	69%	64%	63%	79%	80%
Cooking	Electricity	65%	78%	70%	76%	86%	87%
	Natural gas	29%	18%	25%	20%	12%	11%
	Oil	0%	0%	0%	0%	0%	0%
	Other	6%	4%	6%	4%	2%	2%
	None	0%	0%	0%	0%	0%	0%
Dryer	Electricity	54%	64%	55%	65%	66%	72%
	Natural gas	14%	15%	15%	14%	18%	17%
	None	32%	22%	30%	21%	16%	11%
Dishwasher	Electricity	47%	56%	48%	62%	81%	88%
	None	53%	44%	52%	38%	19%	12%
Clothes washer	Electricity	81%	92%	93%	95%	85%	89%
	None	19%	9%	7%	5%	15%	11%

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1.
(2) Saturations do not always add to one, such as for refrigerators, where many homes have two refrigerators.
(3) Central and Room Heating saturations are combined for Existing Equipment in Existing houses and for New Equipment in New Houses, but are separated for New equipment in Existing Houses
(4) Saturations for lighting and miscellaneous have no physical meaning and are omitted here.

Table A.15: 7% Market Discount Rate Case (Case 4) forecast of residential equipment saturations by end-use, housing type and equipment type

	Housing:	*Existing*	*Existing*	*Existing*	*Existing*	*New*	*New*
	Equipment:	*Existing*	*Existing*	*New*	*New*	*New*	*New*
	Year:	*1990*	*2030*	*1990*	*2030*	*1990*	*2030*
Central heat	Electricity	11%	11%	9%	9%	18%	18%
	Natural gas	46%	46%	52%	51%	39%	39%
	Oil	15%	15%	23%	21%	1%	1%
	Other	3%	3%	4%	3%	1%	1%
	HP	9%	9%	13%	15%	30%	29%
	None	0%	0%	0%	0%	0%	0%
Room heat	Electricity	6%	6%	29%	30%	10%	10%
	Natural gas	8%	8%	63%	63%	1%	1%
	Oil	1%	1%	4%	4%	0%	0%
	Other	1%	1%	3%	3%	1%	1%
	None	0%	0%	1%	1%	0%	0%
Air conditioning	Room	36%	37%	40%	40%	11%	11%
	Central	34%	35%	39%	41%	49%	50%
	HP	9%	9%	7%	7%	30%	29%
	None	21%	19%	14%	12%	11%	10%
Water heat	Electricity	45%	45%	42%	42%	62%	62%
	Natural gas	51%	51%	54%	54%	35%	35%
	Oil	2%	2%	2%	2%	2%	2%
	Other	2%	2%	2%	2%	1%	1%
	None	1%	1%	0%	0%	0%	0%
Refrigerators	Electricity	119%	119%	120%	120%	118%	118%
	None	6%	6%	6%	5%	8%	7%
Freezers	Electricity	32%	32%	39%	39%	21%	22%
	None	68%	68%	61%	61%	79%	78%
Cooking	Electricity	78%	78%	76%	76%	87%	87%
	Natural gas	18%	18%	20%	20%	11%	11%
	Oil	0%	0%	0%	0%	0%	0%
	Other	4%	4%	4%	4%	2%	2%
	None	0%	0%	0%	0%	0%	0%
Dryer	Electricity	27%	28%	26%	29%	40%	42%
	Natural gas	31%	31%	29%	30%	36%	35%
	None	42%	41%	44%	42%	25%	23%
Dishwasher	Electricity	54%	56%	59%	62%	87%	88%
	None	46%	44%	41%	38%	13%	12%
Clothes washer	Electricity	60%	61%	73%	73%	33%	37%
	None	40%	39%	27%	27%	67%	63%

(1) Source: LBL Residential Energy Model, using input assumptions from Table A.1 and a 7% real discount rate for all consumer decisions regarding efficiency choice.
(2) Saturations do not always add to one, such as for refrigerators, where many homes have two refrigerators.
(3) Central and Room Heating saturations are combined for Existing Equipment in Existing houses and for New Equipment in New Houses, but are separated for New equipment in Existing Houses
(4) Saturations for lighting and miscellaneous have no physical meaning and are omitted here.

Table A.16: U.S. residential primary energy use by fuel and policy case in 1990 and 2030

Case #	Resource energy consumption (Quads) Electricity	Natural gas	Oil	Other	Total	Primary energy use (% of 1990) Electricity	Natural gas	Oil	Other	Total	Primary energy use (% of total) Electricity	Natural gas	Oil	Other	Total
1990 energy	9.83	4.84	1.13	0.17	15.97	*100%*	*100%*	*100%*	*100%*	*100%*	62%	30%	7%	1%	100%
2030 energy															
0	15.24	4.18	1.71	0.11	21.23	155%	86%	151%	64%	133%	72%	20%	8%	1%	100%
1	14.48	4.10	1.68	0.11	20.37	147%	85%	149%	63%	128%	71%	20%	8%	1%	100%
2	14.27	4.06	1.69	0.11	20.12	145%	84%	150%	63%	126%	71%	20%	8%	1%	100%
3	13.61	3.89	1.69	0.11	19.29	138%	80%	150%	63%	121%	71%	20%	9%	1%	100%
4	12.50	3.76	1.54	0.09	17.88	127%	78%	136%	50%	112%	70%	21%	9%	0%	100%
5	12.26	3.72	1.54	0.09	17.60	125%	77%	136%	50%	110%	70%	21%	9%	0%	100%
6	11.64	3.59	1.52	0.09	16.84	118%	74%	135%	51%	105%	69%	21%	9%	1%	100%
7	14.48	4.10	1.68	0.11	20.37	147%	85%	149%	63%	128%	71%	20%	8%	1%	100%
8	14.34	4.05	1.69	0.11	20.18	146%	84%	150%	63%	126%	71%	20%	8%	1%	100%
9	13.89	3.85	1.68	0.11	19.54	141%	80%	149%	63%	122%	71%	20%	9%	1%	100%
10	12.50	3.76	1.54	0.09	17.88	127%	78%	136%	50%	112%	70%	21%	9%	0%	100%
11	12.33	3.71	1.54	0.09	17.67	125%	77%	136%	50%	111%	70%	21%	9%	0%	100%
12	11.89	3.56	1.52	0.09	17.06	121%	74%	135%	50%	107%	70%	21%	9%	1%	100%
13	14.48	4.10	1.68	0.11	20.37	147%	85%	149%	63%	128%	71%	20%	8%	1%	100%
14	14.42	4.04	1.69	0.11	20.24	147%	83%	150%	63%	127%	71%	20%	8%	1%	100%
15	14.22	3.82	1.68	0.11	19.82	145%	79%	149%	62%	124%	72%	19%	8%	1%	100%
16	12.50	3.76	1.54	0.09	17.88	127%	78%	136%	50%	112%	70%	21%	9%	0%	100%
17	12.41	3.71	1.53	0.09	17.74	126%	77%	136%	50%	111%	70%	21%	9%	0%	100%
18	12.18	3.53	1.52	0.09	17.32	124%	73%	135%	49%	108%	70%	20%	9%	0%	100%
19	13.89	4.19	1.69	0.11	19.88	141%	86%	150%	65%	124%	70%	21%	9%	1%	100%
20	13.83	4.11	1.69	0.11	19.74	141%	85%	150%	64%	124%	70%	21%	9%	1%	100%
21	13.61	3.89	1.69	0.11	19.29	138%	80%	150%	63%	121%	71%	20%	9%	1%	100%
22	11.90	3.83	1.54	0.09	17.36	121%	79%	137%	51%	109%	69%	22%	9%	1%	100%
23	11.83	3.77	1.54	0.09	17.23	120%	78%	137%	51%	108%	69%	22%	9%	1%	100%
24	11.64	3.59	1.52	0.09	16.84	118%	74%	135%	51%	105%	69%	21%	9%	1%	100%

(1) policy cases are those shown in Table A.3.

(2) energy consumption is calculated using the LBL Residential Energy Model.

(3) 1990 energy consumption is taken from the reference case (Case 1).

Table A.17: U.S. residential total primary energy use by policy case 1990 to 2030

	Resource energy consumption (Quadrillion Btus)					*Resource energy (as % of Case 1 1990)*					*Resource energy (as % of Reference Case--Case 1)*					*2030/1990*	*Average annual growth rate 1990-2030*
Case #	*1990*	*2000*	*2010*	*2020*	*2030*	*1990*	*2000*	*2010*	*2020*	*2030*	*1990*	*2000*	*2010*	*2020*	*2030*		
0	16.0	17.0	18.5	20.1	21.2	100%	106%	116%	126%	133%	100%	103%	105%	105%	104%	1.33	0.7%
1	***16.0***	16.5	17.7	19.2	20.4	***100%***	104%	111%	120%	128%	***100%***	***100%***	***100%***	***100%***	***100%***	1.28	0.6%
2	15.9	16.4	17.5	18.9	20.1	100%	103%	110%	119%	126%	100%	99%	99%	99%	99%	1.27	0.6%
3	15.7	15.9	16.9	18.2	19.3	98%	100%	106%	114%	121%	98%	96%	96%	95%	95%	1.23	0.5%
4	15.9	15.3	15.6	16.8	17.9	100%	96%	98%	105%	112%	100%	92%	88%	88%	88%	1.12	0.3%
5	15.9	15.1	15.4	16.6	17.6	99%	95%	97%	104%	110%	99%	91%	87%	87%	86%	1.11	0.3%
6	15.7	14.6	14.8	15.9	16.8	98%	91%	93%	100%	105%	98%	88%	84%	83%	83%	1.07	0.2%
7	16.0	16.5	17.7	19.2	20.4	100%	104%	111%	120%	128%	100%	100%	100%	100%	100%	1.28	0.6%
8	15.9	16.4	17.5	19.0	20.2	100%	103%	110%	119%	126%	100%	99%	99%	99%	99%	1.27	0.6%
9	15.7	15.9	17.0	18.3	19.5	98%	100%	106%	115%	122%	98%	96%	96%	96%	96%	1.24	0.5%
10	15.9	15.3	15.6	16.8	17.9	100%	96%	98%	105%	112%	100%	92%	88%	88%	88%	1.12	0.3%
11	15.9	15.1	15.4	16.6	17.7	99%	95%	97%	104%	111%	99%	91%	87%	87%	87%	1.11	0.3%
12	15.7	14.6	14.9	16.0	17.1	98%	91%	93%	100%	107%	98%	88%	84%	84%	84%	1.09	0.2%
13	16.0	16.5	17.7	19.2	20.4	100%	104%	111%	120%	128%	100%	100%	100%	100%	100%	1.28	0.6%
14	15.9	16.4	17.5	19.0	20.2	100%	103%	110%	119%	127%	100%	99%	99%	99%	99%	1.27	0.6%
15	15.7	16.0	17.1	18.6	19.8	98%	100%	107%	116%	124%	98%	96%	97%	97%	97%	1.26	0.6%
16	15.9	15.3	15.6	16.8	17.9	100%	96%	98%	105%	112%	100%	92%	88%	88%	88%	1.12	0.3%
17	15.9	15.1	15.5	16.7	17.7	99%	95%	97%	104%	111%	99%	91%	87%	87%	87%	1.12	0.3%
18	15.7	14.6	15.0	16.2	17.3	98%	92%	94%	102%	108%	98%	89%	85%	85%	85%	1.10	0.2%
19	16.0	16.5	17.5	18.9	19.9	100%	103%	110%	118%	124%	100%	100%	99%	98%	98%	1.24	0.5%
20	15.9	16.4	17.4	18.7	19.7	100%	102%	109%	117%	124%	100%	99%	98%	98%	97%	1.24	0.5%
21	15.7	15.9	16.9	18.2	19.3	98%	100%	106%	114%	121%	98%	96%	96%	95%	95%	1.23	0.5%
22	15.9	15.2	15.5	16.5	17.4	100%	95%	97%	103%	109%	100%	92%	87%	86%	85%	1.09	0.2%
23	15.9	15.1	15.3	16.3	17.2	99%	94%	96%	102%	108%	99%	91%	87%	85%	85%	1.09	0.2%
24	15.7	14.6	14.8	15.9	16.8	98%	91%	93%	100%	105%	98%	88%	84%	83%	83%	1.07	0.2%

(1) policy cases are those shown in Table A.3.

(2) Energy consumption is calculated using the LBL Residential Energy Model.

(3) 1990 energy consumptions differ because policy instruments (ie carbon taxes and the reduction of market discount rates to 7%) are assumed to take effect at the beginning of 1990.

Table A.18: Cumulative primary energy consumption by fuel and scenario (1990-2030)

Case #	*Cumulative Electricity Consumption (Quads)*	*Index relative to Base Case (#1)*	*Cumulative Natural gas Consumption (Quads)*	*Index relative to Base Case (#1)*	*Cumulative Oil Consumption (Quads)*	*Index relative to Base Case (#1)*	*Cumulative LPG/Other Consumption (Quads)*	*Index relative to Base Case (#1)*	*Cumulative Total Consumption (Quads)*	*Index relative to Base Case (#1)*
0	639	*1.05*	217	*1.02*	75	*1.02*	6.5	*1.00*	938	*1.04*
1	611	***1.00***	213	***1.00***	73	***1.00***	6.5	***1.00***	904	***1.00***
2	603	*0.99*	210	*0.99*	73	*1.00*	6.5	*1.00*	894	*0.99*
3	581	*0.95*	202	*0.95*	74	*1.00*	6.5	*1.00*	862	*0.95*
4	540	*0.88*	198	*0.93*	68	*0.93*	5.4	*0.83*	812	*0.90*
5	532	*0.87*	195	*0.92*	68	*0.93*	5.4	*0.83*	801	*0.89*
6	509	*0.83*	188	*0.88*	68	*0.93*	5.4	*0.83*	770	*0.85*
7	611	*1.00*	213	*1.00*	73	*1.00*	6.5	*1.00*	904	*1.00*
8	605	*0.99*	210	*0.99*	73	*1.00*	6.5	*1.00*	895	*0.99*
9	586	*0.96*	201	*0.94*	73	*1.00*	6.5	*0.99*	867	*0.96*
10	540	*0.88*	198	*0.93*	68	*0.93*	5.4	*0.83*	812	*0.90*
11	533	*0.87*	195	*0.92*	68	*0.93*	5.4	*0.83*	802	*0.89*
12	514	*0.84*	188	*0.88*	68	*0.92*	5.4	*0.83*	775	*0.86*
13	611	*1.00*	213	*1.00*	73	*1.00*	6.5	*1.00*	904	*1.00*
14	607	*0.99*	210	*0.98*	73	*1.00*	6.5	*1.00*	897	*0.99*
15	596	*0.97*	200	*0.94*	73	*1.00*	6.4	*0.99*	875	*0.97*
16	540	*0.88*	198	*0.93*	68	*0.93*	5.4	*0.83*	812	*0.90*
17	536	*0.88*	195	*0.91*	68	*0.93*	5.4	*0.83*	804	*0.89*
18	522	*0.86*	187	*0.88*	68	*0.92*	5.4	*0.82*	782	*0.87*
19	596	*0.98*	215	*1.01*	74	*1.00*	6.6	*1.01*	891	*0.99*
20	592	*0.97*	212	*0.99*	74	*1.00*	6.6	*1.01*	884	*0.98*
21	581	*0.95*	202	*0.95*	74	*1.00*	6.5	*1.00*	862	*0.95*
22	525	*0.86*	199	*0.94*	69	*0.94*	5.4	*0.83*	798	*0.88*
23	521	*0.85*	197	*0.92*	68	*0.93*	5.4	*0.83*	791	*0.88*
24	509	*0.83*	188	*0.88*	68	*0.93*	5.4	*0.83*	770	*0.85*

(1) electricity is measured in terms of primary energy, using LBL REM's convention of 11,500 Btus.f/kWh.e

(2) scenarios are described in Table A.3.

Table A.19: U.S. residential carbon emissions by fuel and policy case in 1990 and 2030

Case #	*Carbon emissions (megatonnes C)* Electricity	Natural gas	Oil	Other	Total	*Carbon emissions (% of 1990)* Electricity	Natural gas	Oil	Other	Total	*Carbon emissions (% of total)* Electricity	Natural gas	Oil	Other	Total
1990 emissions	155.6	71.1	22.4	2.5	251.6	*100%*	*100%*	*100%*	*100%*	*100%*	62%	28%	9%	1%	100%
0	297.9	61.4	33.9	1.6	394.8	191%	86%	151%	64%	157%	75%	16%	9%	0%	100%
1	283.1	60.2	33.5	1.6	378.3	182%	85%	149%	63%	150%	75%	16%	9%	0%	100%
2	279.0	59.5	33.5	1.6	373.7	179%	84%	150%	63%	149%	75%	16%	9%	0%	100%
3	266.1	57.0	33.6	1.6	358.3	171%	80%	150%	63%	142%	74%	16%	9%	0%	100%
4	244.4	55.2	30.5	1.3	331.3	157%	78%	136%	50%	132%	74%	17%	9%	0%	100%
5	239.7	54.6	30.5	1.3	326.1	154%	77%	136%	50%	130%	74%	17%	9%	0%	100%
6	227.6	52.7	30.3	1.3	311.9	146%	74%	135%	51%	124%	73%	17%	10%	0%	100%
7	194.5	60.2	33.5	1.6	289.8	125%	85%	149%	63%	115%	67%	21%	12%	1%	100%
8	192.6	59.4	33.5	1.6	287.1	124%	84%	150%	63%	114%	67%	21%	12%	1%	100%
9	186.6	56.6	33.4	1.6	278.2	120%	80%	149%	63%	111%	67%	20%	12%	1%	100%
10	167.9	55.2	30.5	1.3	254.8	108%	78%	136%	50%	101%	66%	22%	12%	0%	100%
11	165.6	54.5	30.5	1.3	251.9	106%	77%	136%	50%	100%	66%	22%	12%	1%	100%
12	159.7	52.3	30.2	1.3	243.4	103%	74%	135%	50%	97%	66%	21%	12%	1%	100%
13	114.5	60.2	33.5	1.6	209.7	74%	85%	149%	63%	83%	55%	29%	16%	1%	100%
14	114.0	59.2	33.5	1.6	208.3	73%	83%	150%	63%	83%	55%	28%	16%	1%	100%
15	112.4	56.0	33.3	1.6	203.3	72%	79%	149%	62%	81%	55%	28%	16%	1%	100%
16	98.8	55.2	30.5	1.3	185.8	64%	78%	136%	50%	74%	53%	30%	16%	1%	100%
17	98.2	54.4	30.5	1.3	184.3	63%	77%	136%	50%	73%	53%	30%	17%	1%	100%
18	96.3	51.8	30.1	1.2	179.6	62%	73%	135%	49%	71%	54%	29%	17%	1%	100%
19	109.8	61.5	33.6	1.6	206.5	71%	86%	150%	65%	82%	53%	30%	16%	1%	100%
20	109.3	60.4	33.6	1.6	205.0	70%	85%	150%	64%	81%	53%	29%	16%	1%	100%
21	107.6	57.0	33.6	1.6	199.8	69%	80%	150%	63%	79%	54%	29%	17%	1%	100%
22	94.1	56.2	30.7	1.3	182.2	60%	79%	137%	51%	72%	52%	31%	17%	1%	100%
23	93.6	55.3	30.6	1.3	180.8	60%	78%	137%	51%	72%	52%	31%	17%	1%	100%
24	92.1	52.7	30.3	1.3	176.3	59%	74%	135%	51%	70%	52%	30%	17%	1%	100%

(1) policy cases are those shown in Table A.3.

(2) carbon emissions are the result of the emissions factors from Table A.4 and energy consumption calculated using the LBL Residential Energy Model.

Table A.20: U.S. residential carbon emissions by policy case 1990 to 2030

	Carbon emissions (megatonnes C)					*Carbon emissions (as % of Case 1 1990)*					*Carbon emissions (as % of Reference Case--Case 1)*					*2030/1990*	*Average annual growth rate 1990-2030*
Case #	*1990*	*2000*	*2010*	*2020*	*2030*	*1990*	*2000*	*2010*	*2020*	*2030*	*1990*	*2000*	*2010*	*2020*	*2030*		
0	252	270	310	355	395	100%	107%	123%	141%	157%	100%	103%	105%	105%	104%	1.57	1.1%
1	*252*	263	296	339	378	*100%*	104%	118%	135%	150%	*100%*	*100%*	*100%*	*100%*	*100%*	1.50	1.0%
2	251	261	293	335	374	100%	104%	116%	133%	149%	100%	99%	99%	99%	99%	1.49	1.0%
3	248	253	283	323	358	98%	101%	113%	128%	142%	98%	96%	96%	95%	95%	1.45	0.9%
4	251	243	262	298	331	100%	96%	104%	118%	132%	100%	92%	88%	88%	88%	1.32	0.7%
5	250	240	258	293	326	99%	95%	103%	117%	130%	99%	91%	87%	86%	86%	1.30	0.7%
6	247	232	248	281	312	98%	92%	99%	112%	124%	98%	88%	84%	83%	82%	1.26	0.6%
7	252	257	282	293	290	100%	102%	112%	116%	115%	100%	98%	95%	86%	77%	1.15	0.4%
8	250	255	279	290	287	100%	101%	111%	115%	114%	100%	97%	94%	85%	76%	1.15	0.3%
9	248	248	270	281	278	98%	99%	108%	111%	111%	98%	94%	91%	83%	74%	1.12	0.3%
10	251	238	249	257	255	100%	95%	99%	102%	101%	100%	90%	84%	76%	67%	1.01	0.0%
11	250	235	246	254	252	99%	93%	98%	101%	100%	99%	89%	83%	75%	67%	1.01	0.0%
12	247	228	237	245	243	98%	91%	94%	97%	97%	98%	87%	80%	72%	64%	0.99	0.0%
13	252	206	195	202	210	100%	82%	78%	80%	83%	100%	78%	66%	60%	55%	0.83	-0.5%
14	251	204	194	201	208	100%	81%	77%	80%	83%	100%	78%	65%	59%	55%	0.83	-0.5%
15	248	198	189	196	203	98%	79%	75%	78%	81%	98%	75%	64%	58%	54%	0.82	-0.5%
16	251	190	174	179	186	100%	76%	69%	71%	74%	100%	72%	59%	53%	49%	0.74	-0.8%
17	250	188	172	177	184	99%	75%	68%	71%	73%	99%	72%	58%	52%	49%	0.74	-0.8%
18	247	183	167	173	180	98%	73%	66%	69%	71%	98%	69%	56%	51%	47%	0.73	-0.8%
19	252	205	194	200	207	100%	82%	77%	80%	82%	100%	78%	66%	59%	55%	0.82	-0.5%
20	251	203	193	199	205	100%	81%	77%	79%	81%	100%	77%	65%	59%	54%	0.82	-0.5%
21	248	198	187	193	200	98%	79%	74%	77%	79%	98%	75%	63%	57%	53%	0.81	-0.5%
22	251	190	172	177	182	100%	75%	68%	70%	72%	100%	72%	58%	52%	48%	0.73	-0.8%
23	250	188	171	175	181	99%	75%	68%	70%	72%	99%	71%	58%	52%	48%	0.72	-0.8%
24	247	182	166	170	176	98%	72%	66%	68%	70%	98%	69%	56%	50%	47%	0.71	-0.8%

(1) policy cases are those shown in Table A.3.

(2) carbon emissions are the result of the emissions factors from Table A.4 and energy consumption calculated using the LBL Residential Energy Model.

(3) 1990 carbon emissions differ because policy instruments (ie carbon taxes and the reduction of market discount rates to 7%) are assumed to take effect at the beginning of 1990.

Figure A.3a: Total residential primary energy use assuming NES Current Policy Base resource mix for electricity

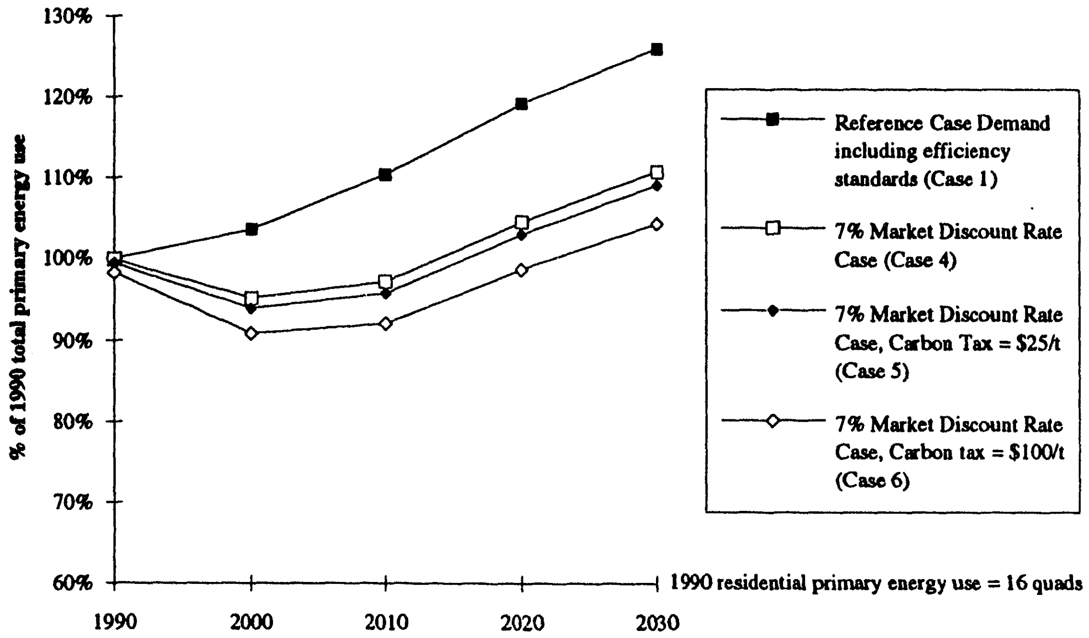


Figure A.3b: Total residential carbon emissions assuming NES Current Policy Base resource mix for electricity

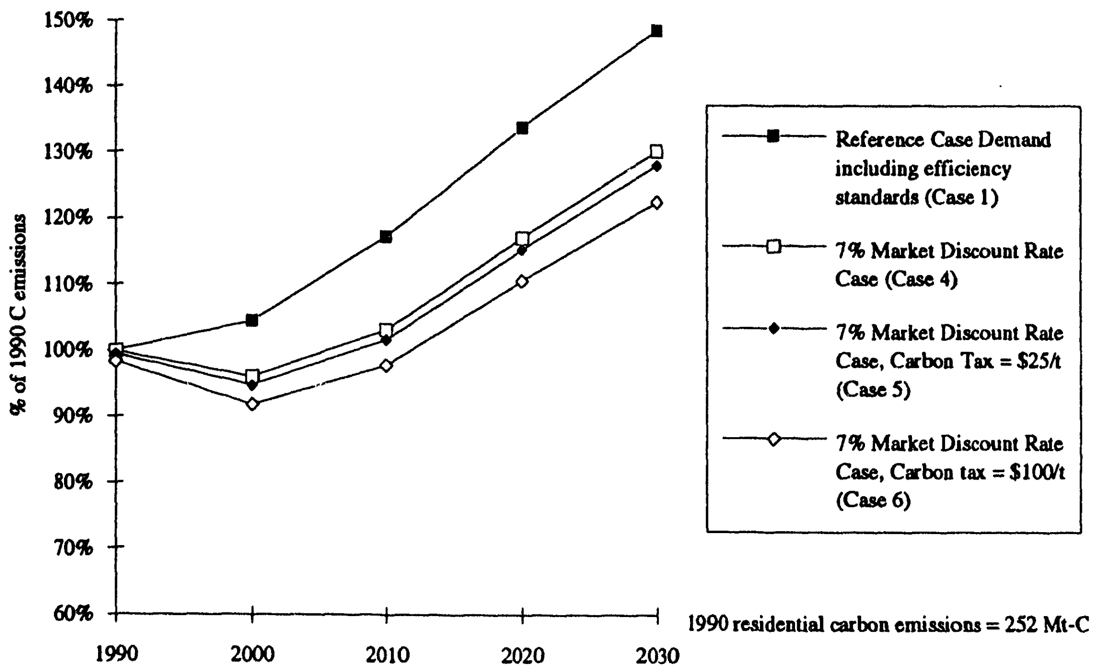


Figure A.4a: Total residential primary energy consumption assuming NES Excursion resource mix for electricity

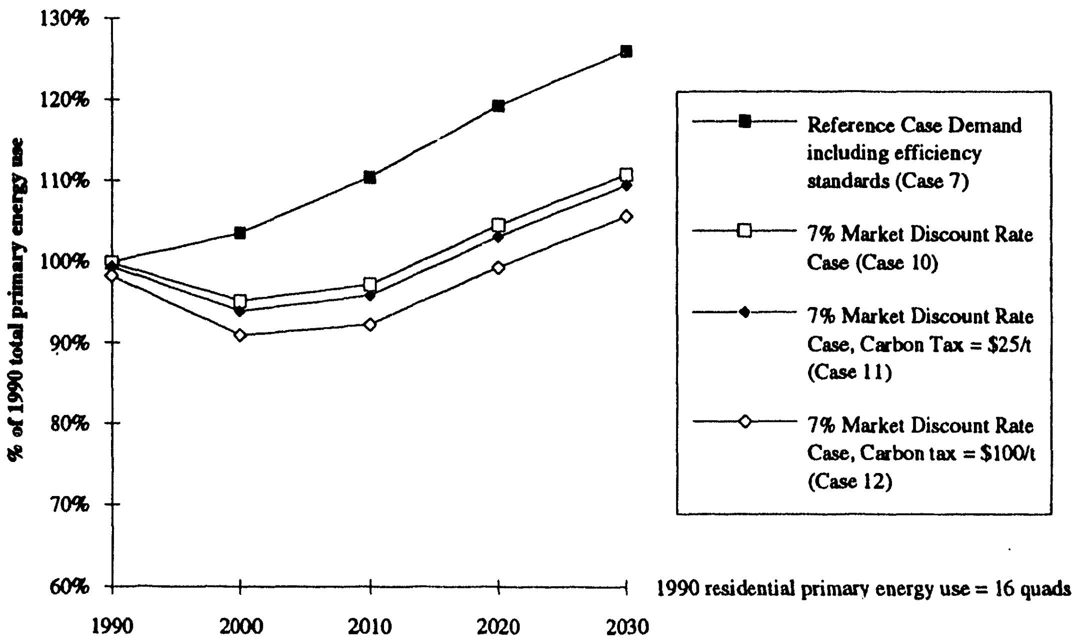


Figure A.4b: Total residential carbon emissions assuming NES Excursion resource mix for electricity

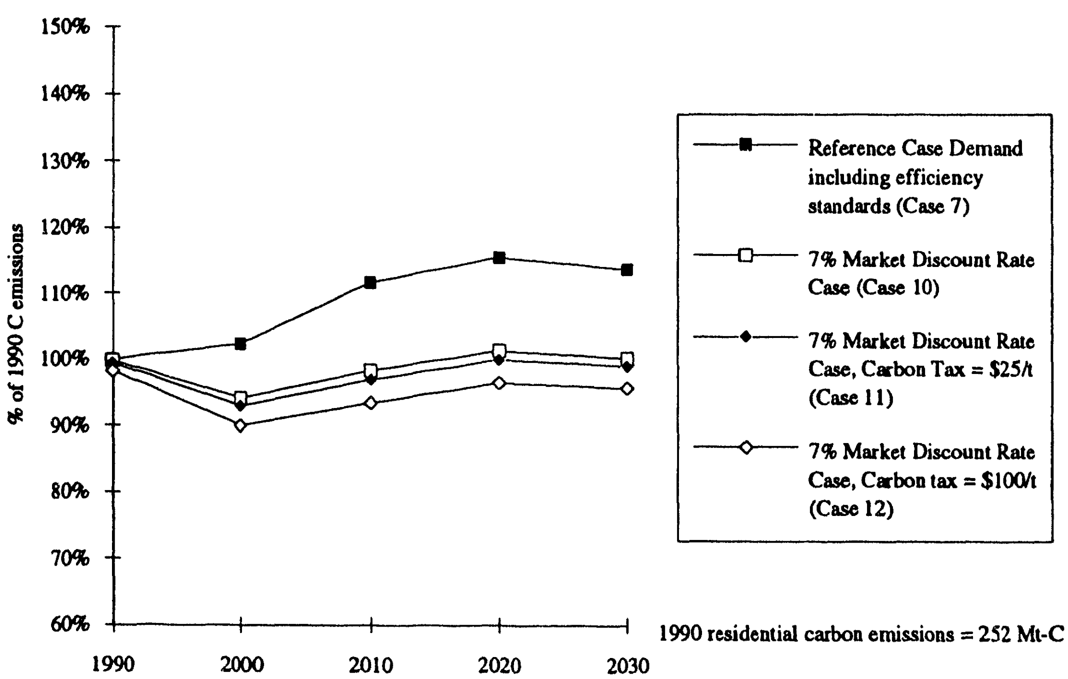


Figure A.5a: Total residential primary energy use assuming 50% reduction in carbon intensity of electricity generation from 1990 levels by 2030

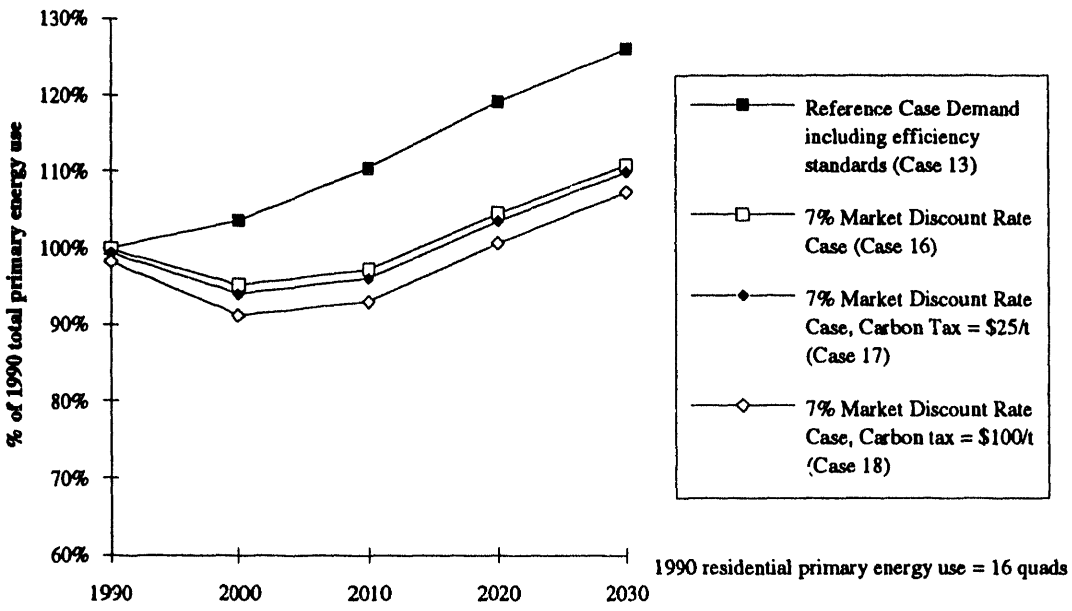


Figure A.5b: Total residential carbon emissions assuming 50% reduction in carbon intensity of electricity generation from 1990 levels by 2030

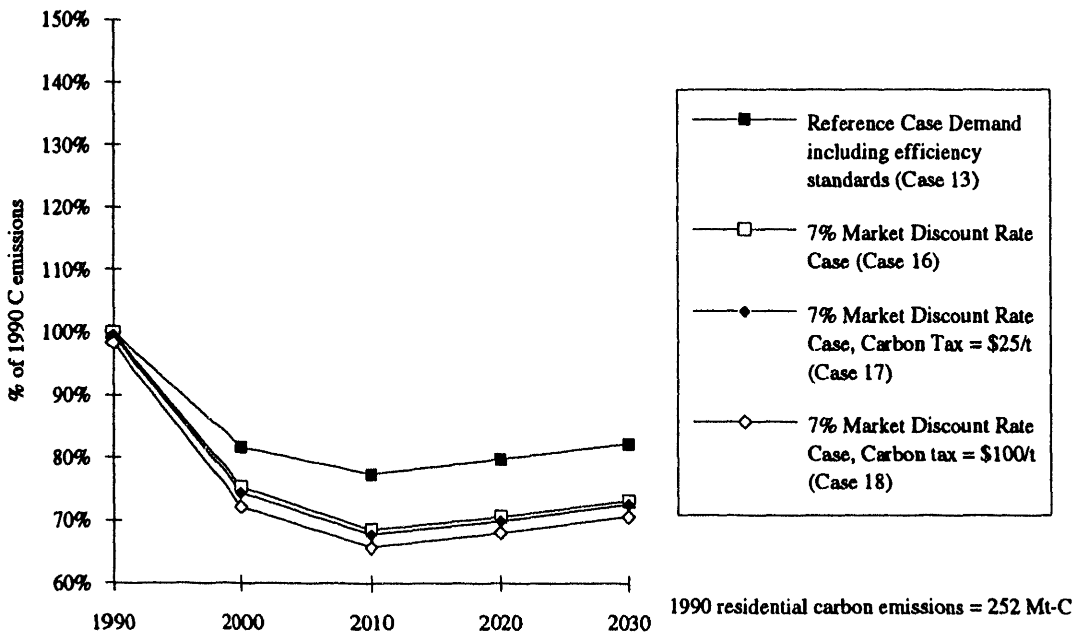


Table A.21: Projected annual carbon tax revenues by scenario
(Billions of 1990 dollars/year)

Case #	*Annual revenues from carbon taxes (Billions of 1990 $/yr)* 1990	2000	2010	2020	2030
0	0	0	0	0	0
1	0	0	0	0	0
2	6.3	6.5	7.3	8.4	9.3
3	25	25	28	32	36
4	0	0	0	0	0
5	6.3	6.0	6.5	7.3	8.2
6	25	23	25	28	31
7	0	0	0	0	0
8	6.3	6.4	7.0	7.2	7.2
9	25	25	27	28	28
10	0	0	0	0	0
11	6.3	5.9	6.2	6.4	6.3
12	25	23	24	25	24
13	0	0	0	0	0
14	6.3	5.1	4.8	5.0	5.2
15	25	20	19	20	20
16	0	0	0	0	0
17	6.3	4.7	4.3	4.4	4.6
18	25	18	17	17	18
19	0	0	0	0	0
20	6.3	5.1	4.8	5.0	5.1
21	25	20	19	19	20
22	0	0	0	0	0
23	6.3	4.7	4.3	4.4	4.5
24	25	18	17	17	18

(1) carbon emissions from Table A.20 are used with appropriate C taxes to estimate total revenues.

Table A.22: Effect of carbon taxes on primary energy use and carbon emissions in 2030 relative to comparable case without C tax

		2030 Energy		*Ratio*	*2030 Carbon*		*Ratio*
		25$/t tax	*100$/t tax*	*100$/25$*	*25$/t tax*	*100$/t tax*	*100$/25$*
Electricity Reference case	Supply side case I	-1.4%	-6.0%	4.2	-1.4%	-6.0%	4.2
	Supply side case II	-1.0%	-4.0%	4.2	-1.0%	-4.0%	4.2
	Supply side case III	-0.4%	-1.8%	4.2	-0.4%	-1.8%	4.2
Electricity 7% market discount rate case	Supply side case I	-1.9%	-6.8%	3.6	-1.9%	-6.8%	3.6
	Supply side case II	-1.3%	-4.9%	3.7	-1.3%	-4.9%	3.7
	Supply side case III	-0.7%	-2.5%	3.7	-0.7%	-2.5%	3.7
Gas Reference case	Supply side case I	-1.1%	-5.3%	4.6	-1.1%	-5.3%	4.6
	Supply side case II	-1.4%	-6.1%	4.4	-1.4%	-6.1%	4.4
	Supply side case III	-1.7%	-7.0%	4.2	-1.7%	-7.0%	4.2
Gas 7% market discount rate case	Supply side case I	-1.0%	-4.5%	4.7	-1.0%	-4.5%	4.7
	Supply side case II	-1.2%	-5.2%	4.4	-1.2%	-5.2%	4.4
	Supply side case III	-1.4%	-6.0%	4.3	-1.4%	-6.0%	4.3
Total primary Reference case	Supply side case I	-1.2%	-5.3%	4.3	-1.2%	-5.3%	4.3
	Supply side case II	-1.0%	-4.1%	4.3	-0.9%	-4.0%	4.3
	Supply side case III	-0.6%	-2.7%	4.3	-0.7%	-3.1%	4.4
Total primary 7% market discount rate case	Supply side case I	-1.5%	-5.8%	3.8	-1.6%	-5.9%	3.8
	Supply side case II	-1.2%	-4.6%	3.9	-1.1%	-4.5%	3.9
	Supply side case III	-0.8%	-3.1%	4.0	-0.8%	-3.3%	4.1

(1) Supply Side case 1 = Current Policy Base carbon burdens, Supply Side case 2 = NES Excursion carbon burdens, and Supply Side case 3 = carbon burdens reduced 50% relative to 1990 levels by 2030

APPENDIX B: CALCULATION OF SUPPLY SIDE COSTS

Table B.1 shows a simplified busbar cost calculation for the five fossil-fired generation technologies shown in Figure B.1.[8]

Fuel costs, capital costs, and physical parameters are those prevailing in 2010, according to US DOE (1991/1992). We did discover unexpected differences between US DOE (1991/1992) and US DOE (1991b) in terms of capital cost and heat rate assumptions, particularly for advanced coal technologies. We used the former reference in all cases, because it gave more detailed descriptions of the cost assumptions.

We used a nominal capital charge rate of 15%, which roughly corresponds to typical capital charge rates for utilities using a real discount rate around 7%. The busbar cost calculations shown here illustrate the relative importance of various carbon taxes compared to the delivered cost of electricity from various fossil-fired power plants. They are not used elsewhere in the analysis.

Reserve margin savings.

To the extent that modularity can reduce reserve margin requirements, it will lower power costs. We have approximated this effect in our busbar calculations by including a reserve margin cost for each technology that reflects the effective load carrying capability (ELCC) of each power plant (EPRI 1986, Garver 1966). The ELCC adjustment adds the appropriate amount of reserve margin (in combustion turbines) to keep the system as reliable as it was before the power plant was added.

The ELCC adjustment factor (the inverse of which is known as the Capability Ratio) is a function of the reliability of the power plant and the reliability and size of the power system in which the power plant is embedded. Equation B.1 shows how the capability ratio is used to account for reliability effects for technology X:

$$\text{RMA (DM/kW/yr)} = ((CR_X - 1)\, FC_{CT} + (CR_{CT} - 1)\, FC_{CT})) \tag{B.1}$$

where RMA = Reserve Margin Adjustment (DM/kW/yr)

CR_X = capability ratio of technology X

CR_{CT} = capability ratio of a combustion turbine, and

FC_{CT} = annualized fixed costs of a combustion turbine (DM/kW/yr).

This approach assumes that combustion turbines are the marginal resource added to improve reliability. The first term in the parentheses corrects for the reliability of technology X, while the second term accounts for the imperfect reliability of the combustion turbine.

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[8] Aside from Figure B.1, there is no other use of these calculations in this report.

Capital cost including interest

To calculate *capital cost including interest,* we use a formula from the EPRI technical assessment guide (TAG) to calculate the actual cost of a power plant, incorporating real cost escalation and interest during construction (EPRI 1989). The formula for Total Plant Investment (TPI) under these circumstances is:

$$TPI = TPC \frac{(Z^N - 1)}{(Z - 1) N} \quad \text{(B.2)}$$

where TPC is the overnight capital cost in 1st year of operation, defined above,

$$Z = \frac{(1+d)}{(1+e)} = \frac{(1 + \text{real discount rate})}{(1 + \text{real escalation rate})}$$

and N = lead time of power plant.

When the real escalation rate during construction equals zero, Equation B.2 reduces to

$$TPI = TPC \frac{((1+d)^N - 1)}{d\ N} \quad \text{(B.3)}$$

The construction lead time excludes the time-consuming planning and siting process in which, however, only a small portion of total project costs are expended.

Figure B.1 shows the effect of our choices of carbon taxes on the cost of four coal electricity generation technologies and a natural gas-fired Advanced Combined Cycle (ACC) plant. Utility sector fuel prices are those expected to prevail in 2010, using the same source as for our base case forecast of residential fuel prices (for detailed calculations). The $25/tonne carbon tax adds about 0.25 cents/kWh to the delivered cost[9] of the gas ACC plant, and roughly 0.5 ¢/kWh to the cost of the coal technologies. The $100/tonne tax adds about 1¢/kWh (roughly 15%) to the cost of the gas ACC, and about 2¢/kWh (25 to 30%) to the cost of the coal plants.

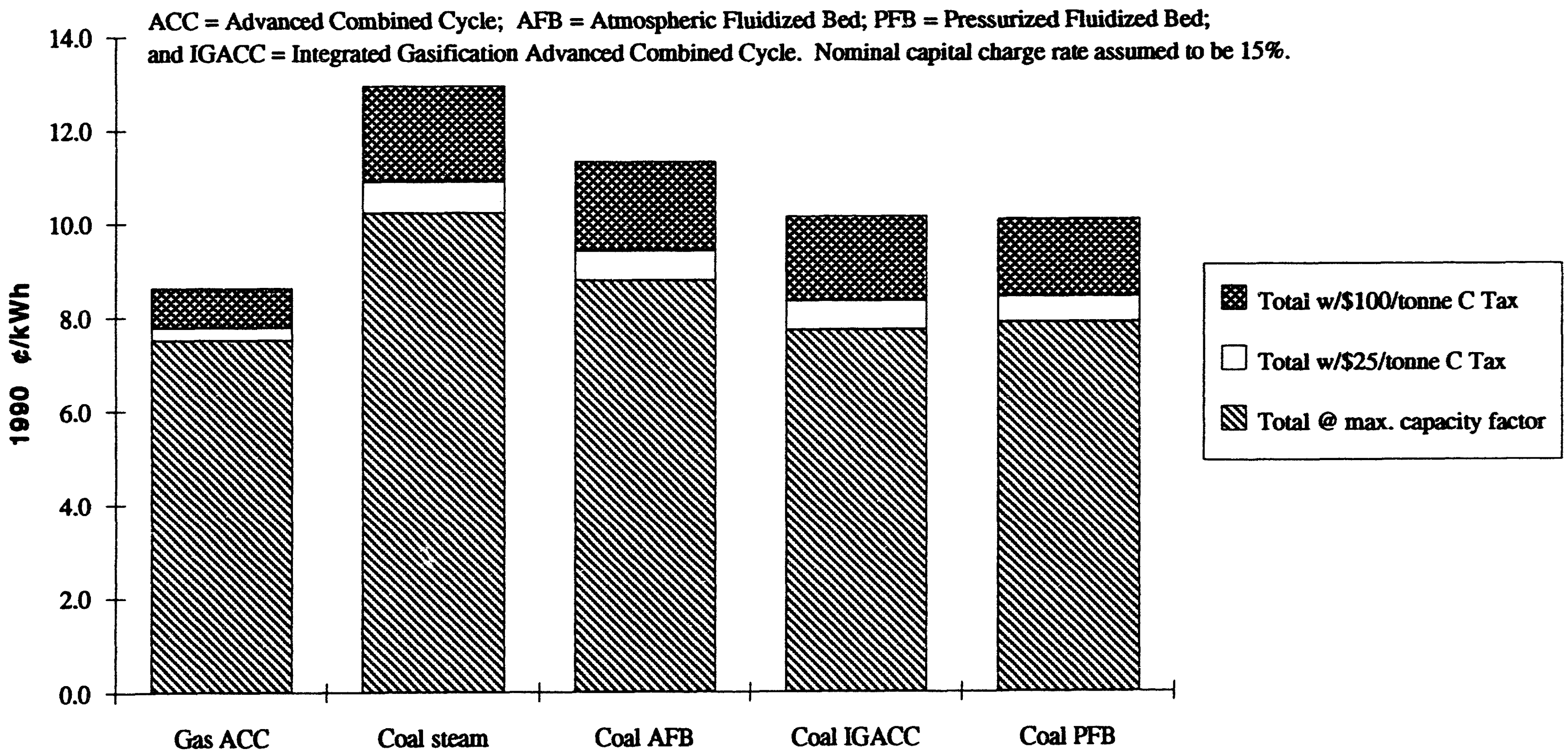
[9]Delivered costs include the NES assumption of electrical transmission and distribution (T&D) losses of 7.5%, but do not include the capital cost of the T&D system.

Table B.1: Busbar costs of selected fossil-fired electricity generation technologies (2010 fuel prices and capital costs)

	Gas ACC	*Coal ST*	*Coal AFB*	*Coal IGACC*	*Coal PFB*
PHYSICAL PARAMETERS					
Total Electric Capacity (MWe)	250	500	250	250	250
Lifetime (Years)	30	30	30	30	30
Construction Lead Time (Years)	3	6	5	4	4
Capacity Factor	70%	70%	70%	70%	70%
Equivalent Unplanned Outage Rate	7.5%	19.5%	16.4%	13.9%	18.9%
Equivalent Availability	90.5%	80.6%	81.3%	85.5%	85.5%
ELCC (MW)	229	381	204	211	198
Heat Rate (kWh heat in/kWh elect. out)	2.22	3.03	2.86	2.70	2.46
Efficiency	45.1%	33.0%	35.0%	37.0%	40.6%
FIXED COSTS					
Nominal Fixed Charge Rate	0.150	0.150	0.150	0.150	0.150
Overnight Capital Cost ($/kW) (2010)	640	1535	1300	1280	1200
Additional NOx Control Cost ($/kW)	75	75	75	75	75
Net Capital Cost ($/kW)	715	1610	1375	1355	1275
Net Cap Cost Including Interest ($/kW)	828	2349	1854	1692	1592
Startup ($/kW)	19.66	39.19	40.65	46.97	46.97
Inventory ($/kW)	29.89	28.17	28.96	9.49	9.49
Land ($/kW)	4.79	46.78	98.35	43.52	43.52
Total: Startup, Inventory, Land ($/kW)	54	114	168	100	100
Annualized Capital Cost ($/kW/yr)	132.3	369.5	303.3	268.7	253.7
Capability Ratio	1.092	1.313	1.223	1.183	1.264
Reserve Margin Cost ($/kW/yr)	11.0	29.6	22.0	18.7	25.5
Total Fixed Costs ($/kW/yr)	*143.3*	*399.0*	*325.3*	*287.4*	*279.3*
Total Fixed Costs (¢/kWh)	*2.3*	*6.5*	*5.3*	*4.7*	*4.6*
VARIABLE COSTS					
Incremental O&M (¢/kWh elect.)	0.23	1.17	1.02	0.89	1.30
Addl O&M for NOx Control (¢/kWh elect)	0.20	0.60	0.60	0.60	0.60
Fuel Price ($/kWh fuel)	0.0214	0.0069	0.0069	0.0069	0.0069
Fuel Cost (¢/kWh elect.)	4.7	2.1	2.0	1.9	1.7
Total Variable Costs (¢/kWh)	*5.2*	*3.9*	*3.6*	*3.4*	*3.6*
T&D Adjustment	1.075	1.075	1.075	1.075	1.075
DELIVERED COST (¢/kWh)					
Fixed @ avg. capacity factor	*2.5*	*7.0*	*5.7*	*5.0*	*4.9*
Fixed @ max. capacity factor	*1.9*	*6.1*	*4.9*	*4.1*	*4.0*
Variable	*5.6*	*4.2*	*3.9*	*3.6*	*3.9*
Externality Cost-Carbon Tax @ 25$/t	*0.3*	*0.7*	*0.6*	*0.6*	*0.5*
Externality Cost-Carbon Tax @ 100$/t	*1.1*	*2.7*	*2.6*	*2.4*	*2.2*
Total @ avg. capacity factor	***8.1***	***11.1***	***9.6***	***8.6***	***8.8***
Total w/1¢/lb C Tax	***8.4***	***11.8***	***10.2***	***9.2***	***9.3***
Total w/4¢/lb C Tax	***9.2***	***13.9***	***12.1***	***11.1***	***11.0***
Total @ max. capacity factor	***7.5***	***10.2***	***8.8***	***7.7***	***7.9***
Total w/1¢/lb C Tax	***7.8***	***10.9***	***9.4***	***8.3***	***8.4***
Total w/4¢/lb C Tax	***8.6***	***12.9***	***11.3***	***10.1***	***10.1***
CT Capital Cost ($/kW/yr)	84.03	m =	1000 MW		
CT Capability Ratio	1.039				
Nominal Fixed Charge Rate	15.0%				
T&D Losses	7.5%				

(1) Source for costs: US DOE 1991/1992. All costs expressed in 1990 $.

Figure B.1: Delivered cost of electricity for fossil supply resources in 2010, NES fuel and capital cost assumptions



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