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TRENDS IN CARBON EMISSIONS FROM U.S. RESIDENTIAL AND COMMERCIAL BUILDINGS: IMPLICATIONS FOR POLICY PRIORITIES

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ABSTRACT

The analysis presented here summarizes carbon emissions and changes in those emissions by end-use in residential and commercial buildings. It demonstrates that the single most important area in the buildings sector is the "miscellaneous electricity" end-use. Eliminating growth in this end-use would suffice to keep buildings sector carbon emissions at 1990 levels through 2010. Reductions in all end-uses can be achieved by implementing efficiency standards, research and development, and market conditioning strategies.

INTRODUCTION

This paper helps policy makers decide where in the buildings sector to focus their efforts in meeting President Clinton's stated goal of freezing U.S. carbon emissions at 1990 levels. It takes as axiomatic the need for such emissions reductions, and leaves to other documents the arguments over whether such reductions are desirable or feasible (Krause et al. 1992, Krause et al. 1993).

The analysis presented here summarizes trends in carbon emissions by end-use in residential and commercial buildings, based principally on the U.S. Department of Energy's Annual Energy Outlook (AEO) 1996 (US DOE 1996). The AEO reports energy use by end-use, but does not disaggregate carbon emissions to that level of detail. However, such disaggregation is essential for understanding changes in energy service demand and how such changes affect policy priorities.

METHODOLOGY

Setting priorities for reducing carbon emissions can involve any of a number of criteria. Initial screening should identify those end-uses that

1) represent large absolute carbon emissions (in million metric tonnes of carbon or MMTC),

2) show large percentage growth rates over the analysis period (%/year), and/or

3) show large absolute growth in emissions over the analysis period (MMTC).

Once these key target end-uses are identified, more focused analysis can take place to assess which efficiency technologies have the largest potential savings, the lowest cost, and the greatest likelihood of success in policy implementation. This paper focuses on the initial screening and leaves the more detailed analysis for future work.

Energy demand

Energy demand by end-use is taken from the Annual Energy Outlook 1996 (US DOE 1996). This source is the official forecast of the U.S. Department of Energy, and it explicitly incorporates the efficiency standards as currently implemented but does not include the EPA's voluntary programs (with the possible exception of Green Lights). It represents a widely accepted baseline against which to assess the potential impacts of recently implemented or future programs and policies.

The AEO 96 forecast begins in 1993, but the Clinton Administration's commitment is to freeze carbon emissions at 1990 levels. A 1990 baseline is therefore required. In the residential sector, I used the estimate of 1990 energy use from the Annual Energy Outlook 1994 (US DOE 1994a). For the commercial sector, I estimated 1990 energy use by backcasting from 1993 using the AEO 96 growth rates by end use for the 1993 to 2000 period. This different procedure was required because the methodology and the end-use categories DOE used to estimate commercial sector energy use changed substantially from 1994 to 1996.

The only exception to the use of the AEO forecast is in commercial office equipment. I took office equipment energy use for 1990 directly from Koomey et al. (1995). While the AEO 96 base year energy use for office equipment is comparable to that calculated in Koomey et al., the growth rates in energy use from 1993-2010 are inconsistent with that source. The AEO growth rates have been modified to reflect the results of that more detailed study.

Emissions factors

Carbon emissions factors ("carbon burdens") for electricity for 1995-2010 are taken directly from AEO 96, while those for 1990 are taken from Koomey et al. (1993).[1] After 1995, AEO projects that electricity carbon burdens will remain roughly constant. Carbon burdens for other fuels are taken from US DOE (1994b). All carbon burdens represent direct emissions and are summarized in **Table 1**. Indirect emissions from the extraction, processing, and transportation of these fuels are not included.

Table 1: Direct carbon burdens

Fuel	*Carbon Burden MMTC/quadrillion Btu of site energy*
Natural gas	14.5
Distillate oil	20.0
Residual oil	21.5
Motor gasoline	19.4
LPG	17.2
Kerosene	19.7
Wood/biomass	0
Coal	25.9
Electricity at point of use	
1990	53.3
1995	48.9
2000	48.6
2005	49.7
2010	49.6

(1) Wood/biomass is assumed to be harvested sustainably, resulting in zero net carbon emissions.

[1]The 7% drop in carbon intensity of electric generation between 1990 and 1995 implied by our methodology is also reflected in the Electric Power Annual for 1990 and 1994 (US DOE 1992, US DOE 1995b, US DOE 1995c).

RESULTS

Carbon emissions

Table 2 and **3** summarize the carbon emissions implied by the AEO forecast for residential and commercial sectors, respectively. These tables are the source of the data for the figures that follow.

Figures 1 and **2** summarize carbon emissions by end-use in 1990 for residential and commercial sectors. The top seven end-uses account for about three-quarters of base year residential and commercial sector carbon emissions. Natural gas heating and miscellaneous electricity are the two largest residential end-uses, followed by refrigerators, electric cooling, electric water heating, electric heating, and lighting. In the commercial sector, lighting is by far the largest source of carbon emissions, followed far behind by electric cooling, miscellaneous electricity, natural gas heating, miscellaneous natural gas, electric water heating, and ventilation. Lighting alone is responsible for more than one-quarter of base year commercial sector emissions.

Annual growth in emissions

Figures 3 and **4** summarize annual percentage growth in carbon emissions by end-use from 1990 to 2010 for residential and commercial sectors. For comparison, the arrows on each graph show the annual growth rate for all end-uses together and the annualized growth rate in number of households or commercial sector floor area.[2] End-uses with growth rates larger than those of the building stock are becoming increasingly energy intensive over time, while those with growth rates lower than those of the building stock are becoming less energy intensive over time. Miscellaneous electricity has by far the highest annual growth rate in residential, and the second highest growth rate in commercial.

Absolute growth in emissions

Figures 5 and **6** summarize absolute growth in carbon emissions by end-use from 1990 to 2010 for residential and commercial sectors. The striking result from both graphs is that miscellaneous electricity is projected to contribute virtually all the net growth in carbon emissions in the buildings sector from 1990-2010. This result follows from the relatively large base year emissions for this end-use combined with high annual growth rates.

While growth in many end-uses has been reduced or eliminated by efficiency standards, utility programs, and other government policies, growth in miscellaneous electricity use has traditionally been ignored. This end-use is often treated as an afterthought in even the most detailed bottom-up analyses, in large part because of its complexity. Because it is the category containing previously unknown uses for electricity, understanding it requires constant attention to market data and a deep appreciation for the subtleties of end-use analysis.

[2] There is only one arrow on Figure 3 because both growth rates = 1.1%/year.

One example of an end-use unexpectedly emerging on the scene is the recent explosion in use of standing halogen torchieres.[3] Other technologies falling into the miscellaneous category include home computers, game machines, bread makers, TVs, stereos, VCRs, well pumps, and a host of other devices (Meier et al. 1992).

The forecast for miscellaneous energy use is based on extrapolation of recent trends embodied in the US DOE's market surveys (US DOE 1995a, US DOE 1995d, US DOE 1995e, US DOE 1994c). Because of the compounding nature of exponential growth, such extrapolation is often problematic, particularly in a twenty year forecast. Without extensive data collection and detailed analysis of what is contributing to these recent trends, it is impossible to say whether they will continue or not.

The AEO forecast as a baseline

In my analysis using the AEO forecast, I discovered that implicit in this forecast are a set of efficiency standards that go beyond current levels and represent the forecaster's best judgement as to how the Congressionally-mandated updates of efficiency standards would affect future minimum standards for residential and commercial equipment. The standards implicit in the AEO forecast are shown in **Tables 4** and **5**. In the commercial sector, only the forecast for commercial rooftop air conditioning (AC) has an assumed efficiency standard taking effect after 1994. This standard improves new equipment efficiency by about 16%, which will have a modest effect on total commercial cooling energy use in 2010 (because rooftop ACs are only a part of total cooling energy use). The issue is more important in residential cooling, where the improvement is 15-30% in 2005 over 1990 levels and it affects all cooling energy use. The other two residential end-uses that are substantially affected by these "projected standards" are refrigerators and freezers (the projected standards for furnaces, water heaters, and stoves have only a small effect).

This modelling approach raises issues of double counting when assessing potential impacts of future programs relative to the AEO 96 baseline, particularly in residential cooling, refrigerators, and freezers. Anyone attempting to assess potential impacts from programs for these end-uses should take care to not simply subtract those energy or carbon impacts from the AEO 96 baseline.

WHERE DO WE GO FROM HERE?

The next step is to assess for each end-use the size of the cost effective potential. A general exposition of the methodology for such analysis is contained in Krause et al. (1993), while an example of such analysis is contained in Krause et al. (1995). The latter source estimates costs and potential savings for improving electricity efficiency in Europe. It relies on engineering estimates of costs and savings modified to reflect measured data on field performance of efficiency measures. Technology costs are then adjusted to reflect internal gains, program costs, and transmission and distribution capital cost credits. In all cases, an explicit uncertainty range is defined. Potential savings reflect best available data

[3]These lamps are not explicitly represented in the AEO 96 residential lighting category, and it is doubtful that the rapid growth in the use of such lamps is contained in the AEO forecast (except implicitly in miscellaneous). None of the standard sources of shipment data for lighting technologies even tracks sales of these torchieres. It is only recently that information on shipments of these lamps (15 million in 1994) has become available and the magnitude of the demand growth caused by them become manifest.

on energy service demand growth, business-as-usual trends, and current and advanced technologies.

Similar analysis for the U.S. is essential for setting a policy agenda. Previous analyses (ASE et al. 1991, Atkinson et al. 1992, Brown 1994, Hanford et al. 1994, Koomey et al. 1991, Koomey et al. 1994, Krause et al. 1995, L'Ecuyer et al. 1993, Nadel and Tress 1990, Sezgen et al. 1995, Sezgen et al. 1994, Sezgen and Koomey 1995a, Sezgen and Koomey 1995b) and work currently in progress for the residential and commercial sectors (Koomey et al. 1996b, Koomey et al. 1996c, Vorsatz and Koomey 1996) will result in much of the information needed for such an assessment.

After assessing cost effective potentials, policy instruments must be implemented that focus specifically on the market imperfections impeding adoption of the more efficient devices (Koomey 1990). There is a vast literature that discusses the market imperfections in the building sector from both empirical and theoretical perspectives (DeCanio 1993, Howarth and Andersson 1993, Howarth and Sanstad 1995, Huntington et al. 1994, Jaffe and Stavins 1994, Koomey and Sanstad 1994, Koomey et al. 1996a, Krause et al. 1993, Levine et al. 1995, Lovins 1992, Sanstad et al. 1995, Sanstad and Howarth 1994, Sanstad et al. 1993). This literature as well as the emerging work in program evaluation (Eto et al. 1994) must be brought to bear on program design so that any new programs reflect the lessons of past programs. End-uses are a convenient way to structure such analyses because market imperfections are often common to particular end-use markets.

A combination of policies will generally work most effectively to transform markets. Research and Development (R&D) and so-called "Golden Carrots" facilitate the introduction of new technologies to the market, while government procurement, ENERGY STAR, and efficiency standards encourage the widespread adoption of technologies that are already on the market.

CONCLUSIONS

End-use analysis is essential for determining where to spend limited program implementation dollars. Future analysis will assess potentials for emissions reductions by end-use, as well as associated costs.

The analysis above demonstrates that the single most important area in the buildings sector is the so-called "miscellaneous electricity" end-use. Eliminating growth in this end-use would suffice to keep buildings sector carbon emissions at 1990 levels through 2010. Further work is needed to gather technology and trend data on this end-use and to determine which policy instruments are most likely to be effective.

ACKNOWLEDGEMENTS

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Figure 1: U.S. residential sector carbon emissions by end-use 1990 (million metric tonnes of carbon)

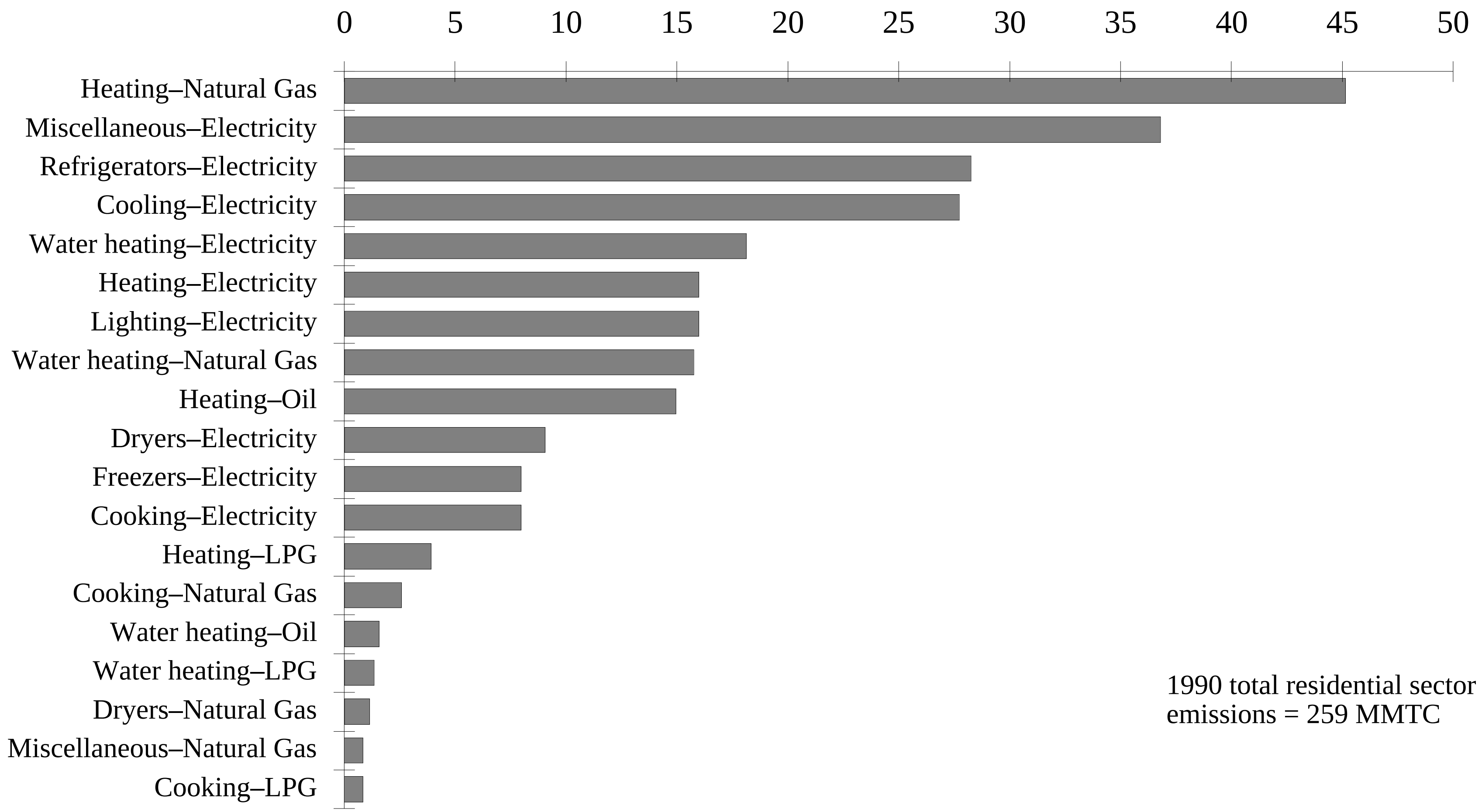

Figure 2: U.S. commercial sector carbon emissions by end-use 1990 (million metric tonnes of carbon)

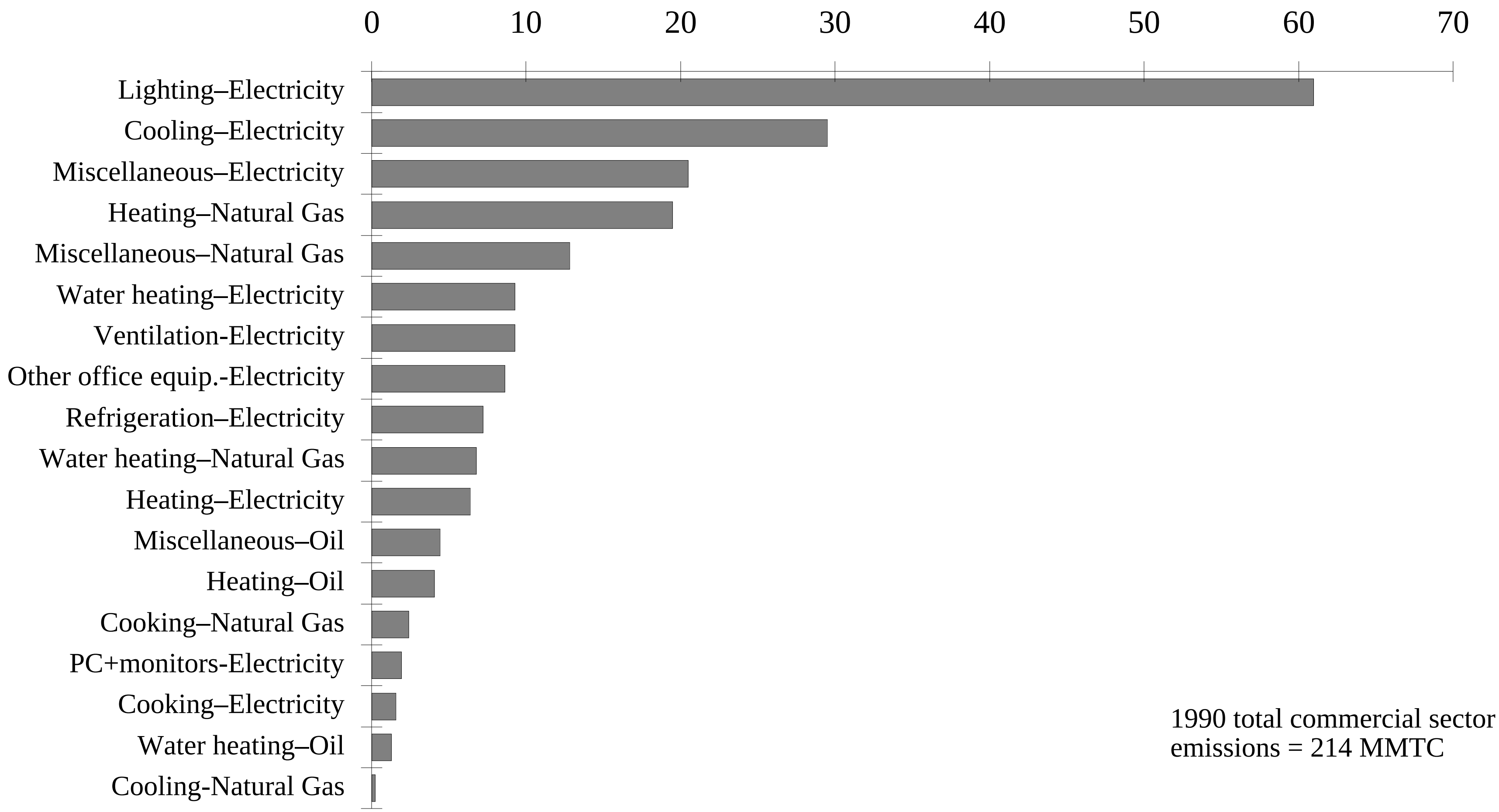

Figure 3: AEO 1996 Projected annual percentage changes in U.S. residential sector carbon emissions by end-use 1990-2010 (%/year)

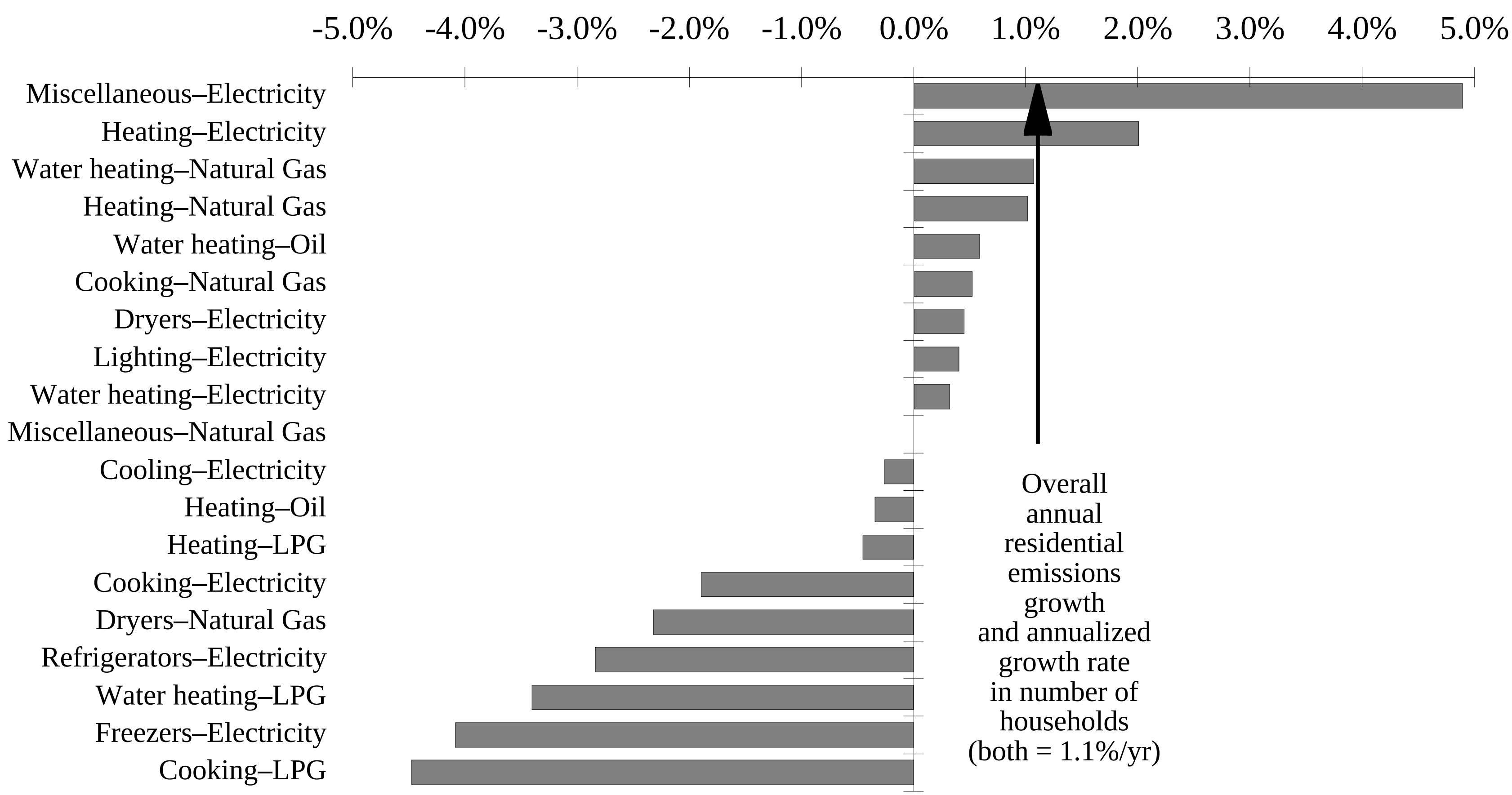

Figure 4: AEO 1996 Projected annual percentage changes in U.S. commercial sector carbon emissions by end-use 1990-2010 (%/year)

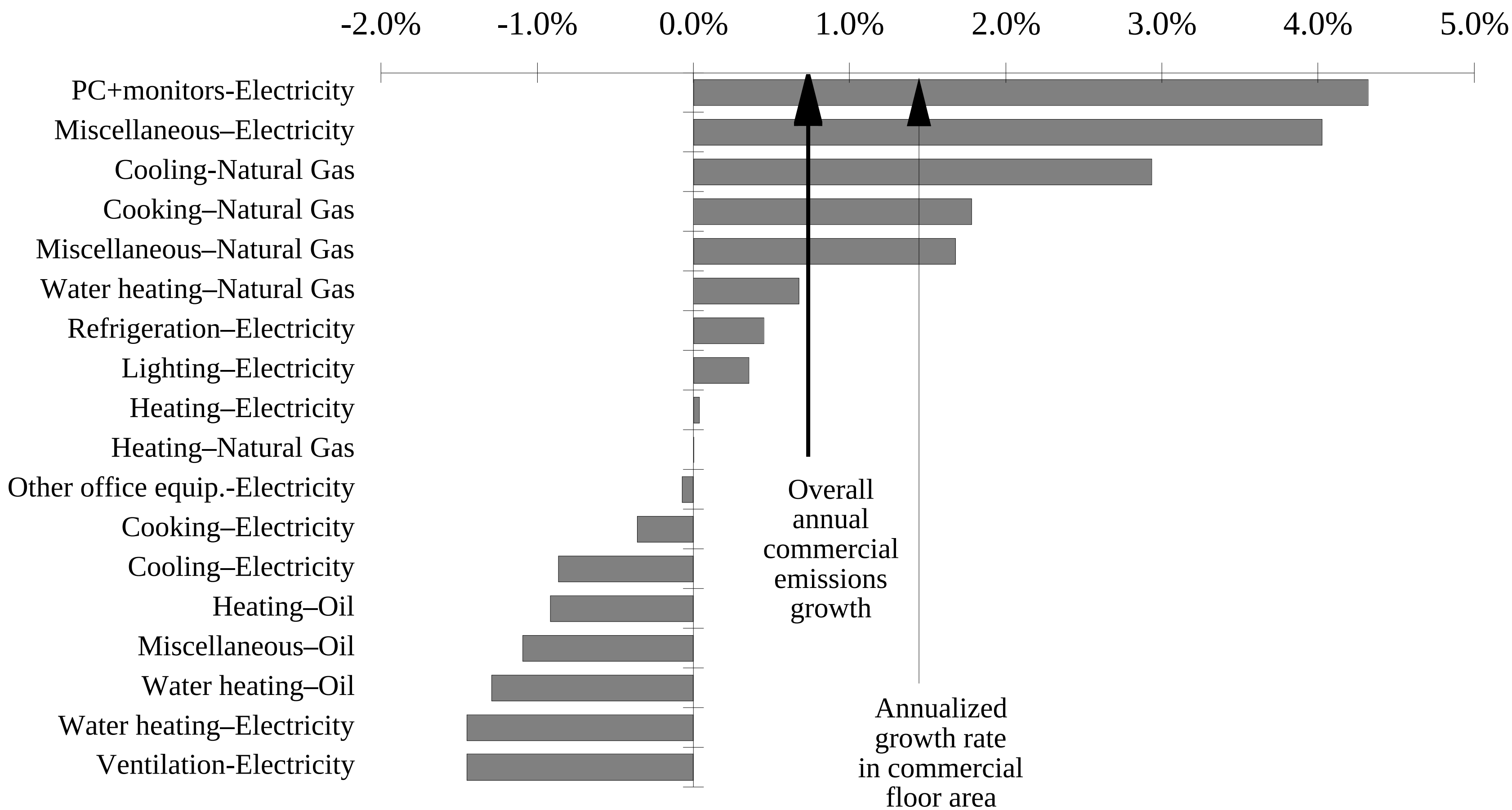

Figure 5: AEO 1996 projected change in U.S. residential sector carbon emissions by end-use 1990-2010 (million metric tonnes of carbon)

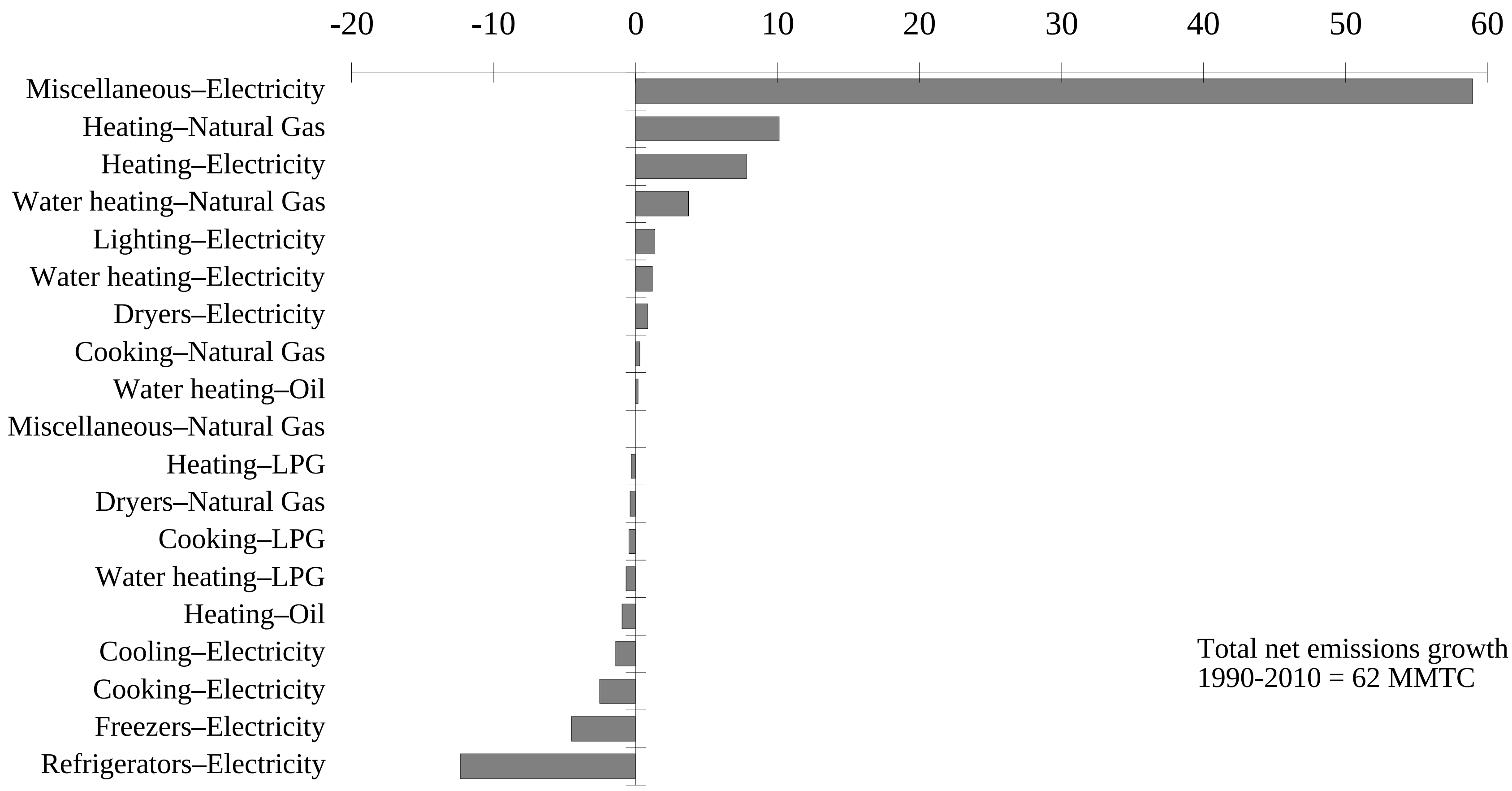

Figure 6: AEO 1996 projected change in U.S. commercial sector carbon emissions by end-use 1990-2010 (million metric tonnes of carbon)

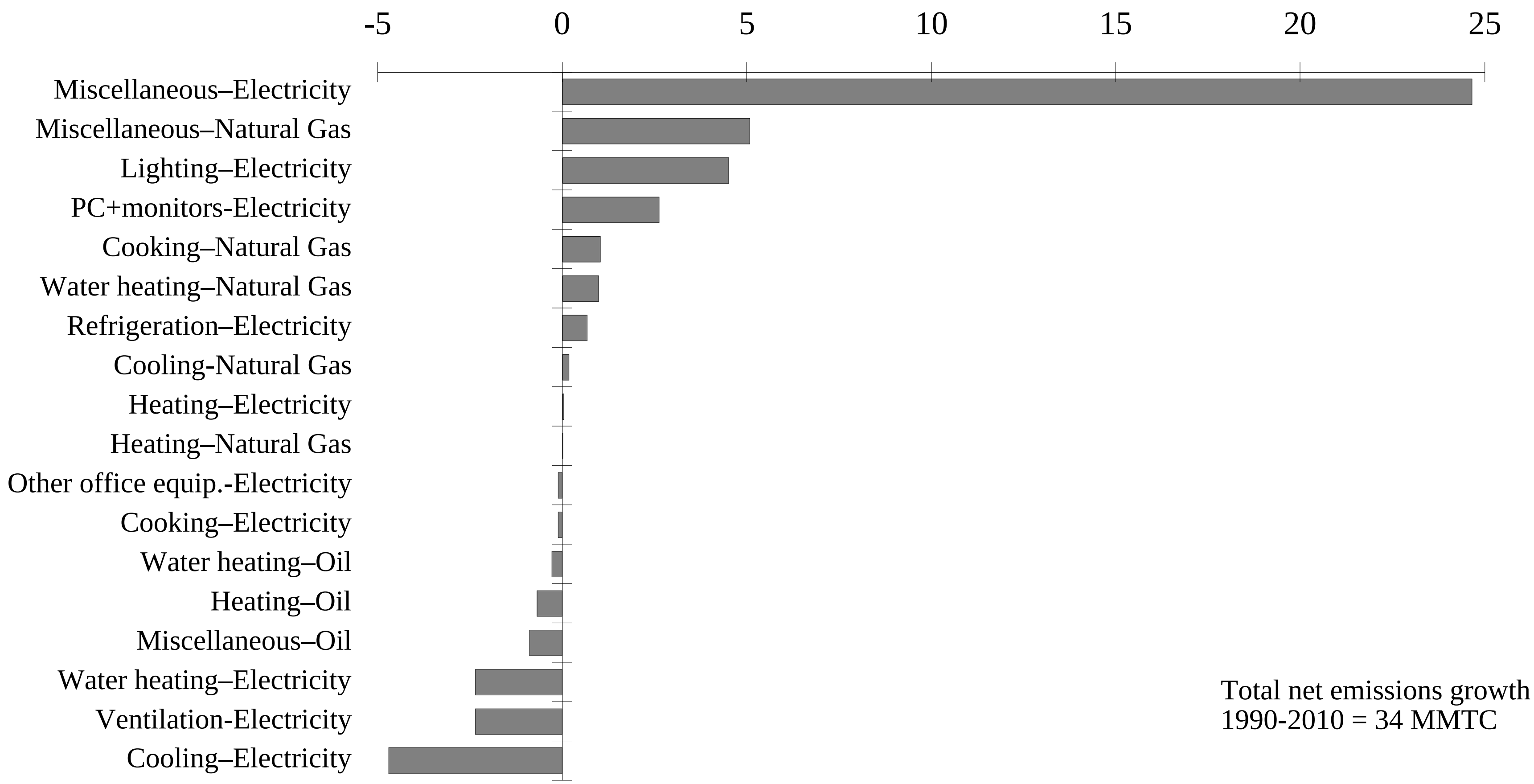

Table 2: U.S. residential sector carbon emissions by end-use (million metric tonnes of carbon)

Fuel	*End-use*	*1990*	*1995*	*2000*	*2005*	*2010*
Electricity	Space heating	16.0	19.6	21.4	22.9	23.8
	Space cooling	27.7	25.4	24.3	25.8	26.3
	Water heating	18.1	17.6	18.0	18.4	19.4
	Refrigeration	28.3	21.5	19.0	17.4	15.9
	Cooking	8.0	4.9	4.9	5.5	5.5
	Clothes Dryers	9.1	8.3	8.8	9.4	9.9
	Freezers	8.0	6.4	4.9	4.0	3.5
	Lighting	16.0	15.6	16.0	16.9	17.4
	Other Uses	36.8	51.3	62.7	78.0	95.8
	Total electric	168.0	170.6	179.9	198.3	217.3
Natural gas	Space heating	45.1	49.5	52.4	53.5	55.3
	Space cooling	0.0	0.0	0.0	0.0	0.0
	Water heating	15.8	18.7	19.0	19.1	19.5
	Cooking	2.6	2.6	2.7	2.9	2.9
	Clothes Dryers	1.2	0.7	0.7	0.7	0.7
	Other Uses	0.9	0.9	0.9	0.9	0.9
	Total gas	65.5	72.4	75.7	77.1	79.3
Distillate oil	Space heating	15.0	14.8	14.8	14.4	14.0
	Water heating	1.6	2.0	2.0	1.8	1.8
	Other Uses	0.0	0.0	0.0	0.0	0.0
	Total oil	16.6	16.8	16.8	16.2	15.8
LPG	Space heating	3.9	4.5	4.3	3.9	3.6
	Water heating	1.4	0.9	0.9	0.7	0.7
	Cooking	0.9	0.3	0.3	0.3	0.3
	Other Uses	0.2	1.0	1.2	1.2	1.2
	Total LPG	6.3	6.7	6.7	6.2	5.8
Renewables	Wood	0.0	0.0	0.0	0.0	0.0
Other fuels	Coal + kerosene	2.8	2.6	2.6	2.4	2.4
Totals		259	269	282	300	321

(1) Site energy 1995-2010 taken from AEO 96 (US DOE 1996). Site energy for 1990 taken from AEO 1994 (US DOE 1994a).
(2) Carbon emissions for electricity 1995-2010 calculated using electricity sector carbon emissions factors implied in AEO 1996. Emissions factors for other fuels taken from US DOE 1994b. Electricity emissions in 1990 calculated using 1990 emissions factor from Koomey et al. 1993.
(3) Other fuels are assumed to be split 1/3 coal 2/3 kerosene for calculating carbon emissions
(4) Wood is assumed to be harvested sustainably, yielding zero net carbon emissions.
(5) Only direct emissions are included. Indirect emissions associated with extraction, transportation, and processing of the fuel are excluded.

Table 3: U.S. commercial sector carbon emissions by end-use
(million metric tonnes of carbon)

Fuel	*End-use*	*1990*	*1995*	*2000*	*2005*	*2010*
Electricity	Space heating	6.4	5.4	5.8	6.0	6.5
	Space cooling	29.5	27.4	24.8	24.9	24.8
	Water heating	9.3	8.3	7.8	7.5	6.9
	Ventilation	8.8	8.3	8.8	9.4	9.9
	Cooking	1.6	1.5	1.5	1.5	1.5
	Lighting	61.0	56.7	58.4	62.1	65.5
	Refrigeration	7.3	6.8	7.3	7.5	7.9
	Office equip. PC	2.0	2.3	2.8	3.7	4.6
	Office equip. non-PC	8.6	8.0	8.1	8.4	8.5
	Other Uses	20.5	29.8	34.0	39.8	45.2
	Total electric	155.0	154.5	159.3	170.6	181.3
Natural gas	Space heating	19.5	18.2	19.1	19.4	19.5
	Space cooling	0.2	0.4	0.4	0.4	0.4
	Water heating	6.8	7.1	7.2	7.5	7.8
	Cooking	2.4	2.7	3.0	3.2	3.5
	Other Uses	12.9	15.6	16.6	17.4	17.9
	Total gas	41.9	44.1	46.4	47.9	49.2
Distillate oil	Space heating	4.1	3.8	3.8	3.6	3.4
	Water heating	1.3	1.0	1.0	1.0	1.0
	Other Uses	4.5	3.4	3.6	3.6	3.6
	Total oil	9.8	8.2	8.4	8.2	8.0
Renewables	Biomass	0.0	0.0	0.0	0.0	0.0
Other fuels	Coal + kerosene	7.3	8.3	8.5	8.7	8.9
Totals		214	215	223	235	247

(1) Site energy 1995-2010 taken from AEO (US DOE 1996). Site energy for 1990 backcast from 1993 using 1993 to 2000 growth rates from AEO (US DOE 1996).
(2) AEO 96 office equipment growth rates 1990-2010 replaced by business-as-usual growth rates from Koomey et al. 1995. Base year office equipment energy use is approximately the same as AEO 96.
(3) Carbon emissions for electricity 1995-2010 calculated using electricity sector carbon emissions factors implied in AEO 1996. Emissions factors for other fuels taken from US DOE 1994b. Electricity emissions in 1990 calculated using 1990 emissions factor from Koomey et al. 1993.
(4) Other fuels are assumed to be split equally between residual oil, LPG, coal, motor gasoline and kerosene for calculating carbon emissions.
(5) Biomass is assumed to be harvested sustainably, yielding zero net carbon emissions.
(6) Only direct emissions are included. Indirect emissions associated with extraction, transportation, and processing of the fuel are excluded.

Table 4: Residential standards, current and projected in AEO 96

		Latest current standard		*Projected standard #1*		*Projected standard #2*		
End-use	*Fuel*	*Year implemented*	*Efficiency level*	*Year implemented*	*Efficiency level*	*Year implemented*	*Efficiency level*	*Units of eff. level*
HP Heating	Electricity	1992	6.79	2005	7.98	2012	8.50	HSPF
HP Cooling	Electricity	1992	10.00	2005	13.00	2012	13.99	SEER
CAC	Electricity	1992	10.00	1998	10.51	2005	13.00	SEER
Furnace	Natural gas	1992	0.78	1998	0.80	2005	0.81	AFUE
RAC	Electricity	1990	8.70	1998	9.01	2005	10.00	EER
Water heating	Electricity	1990	0.86	1998	0.87	2005	0.88	Energy factor
	Natural gas	1990	0.54	1998	0.57	2005	0.60	Energy factor
	Distillate oil	1990	0.53	1998	0.58	N/A	N/A	Energy factor
	LPG	1990	0.54	1998	0.57	2005	0.60	Energy factor
Stove	Electricity	1990	601	1999	577	N/A	N/A	kWh/year
	Natural gas	1990	4.2	1999	3.7	N/A	N/A	MMBtu/yr
	LPG	1990	4.2	1999	3.7	N/A	N/A	MMBtu/yr
Dryer	Electricity	1994	3.01	N/A	N/A	N/A	N/A	EF-lb/kWh
	Natural gas	1994	0.783	N/A	N/A	N/A	N/A	EF-lb/kBtu
Refrigerator	Electricity	1993	683	1998	660	2005	480	kWh/year
Freezer	Electricity	1993	472	1998	394	N/A	N/A	kWh/year

(1) taken directly from the AEO 96/NEMS baseline input file
(2) N/A = not applicable

Table 5: Commercial minimum standards implied in AEO 96 baseline					
End-use	*Fuel*	*Typical new unit efficiency 1990*	*Current standard efficiency 1994*	*EIA projected standard efficiency 1999*	*Units of efficiency level*
ASHP Heating	Electricity	5.80	6.79	N/A	HSPF
ASHP Cooling	Electricity	8.60	10.51	N/A	SEER
Rooftop AC	Electricity	6.79	8.53	9.89	SEER
CAC (resid. type)	Electricity	8.60	10.51	N/A	SEER
RAC (resid. type)	Electricity	7.71	9.01	N/A	EER
Furnace	Distillate oil	0.72	0.81	N/A	AFUE
Boiler	Natural gas	0.68	0.73	N/A	AFUE
	Distillate oil	0.56	0.72	N/A	AFUE
Water heating	Electricity	0.88	0.93	N/A	Energy factor
	Natural gas	0.55	0.73	N/A	Energy factor
	Distillate oil	0.67	0.78	N/A	Energy factor

(1) taken directly from the AEO 96/NEMS baseline input file
(2) There are also some 1994 EPACT lighting standards contained in the AEO 96, which are omitted here because of their complexity.
(3) N/A = not applicable