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Global Climate Change: Carbon Emissions and End-use Energy Demand

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ABSTRACT

The United Nations (Kyoto) Protocol on greenhouse gas emission reductions sets a target for the United States to achieve annual carbon-equivalent emissions of six greenhouse gases over the 2008-2012 period that are 7% below specified baseline years. For carbon dioxide, CO_2, that year is 1990. This report presents an analysis of the potential impacts of the Kyoto Protocol on U.S. energy demand. The analysis focuses on 27 common end-uses — light duty vehicles, residential space heating, industrial direct process heat, etc. — that describe the way energy is used in the United States. Based on a spreadsheet model developed for this report, results are presented that show the reduction in energy demand that would be required by each of the 27 end-uses in order to reduce carbon emissions from energy use to the Kyoto Protocol target levels. The model can be used to evaluate other carbon emission reduction proposals. This study should be of interest to those staff covering the global climate change issue, particularly those interested in the potential consequences of the Protocol on the United States. The report will be updated as other carbon reduction proposals are made.

Global Climate Change: Carbon Emissions and End-use Energy Demand

Summary

The United Nations (Kyoto) Protocol on greenhouse gas emission reductions sets a target for the United States to achieve annual emissions of six greenhouse gases, as measured in terms of their equivalency to carbon dioxide, over the 2008-2012 period that are 7% below specified baseline years. The largest contributor to greenhouse gas emissions is the combustion of fossil fuels for energy production to power a wide variety of end-uses such as automobiles, space heating, and industrial process heat. This report presents an analysis of the potential impacts of meeting the Kyoto Protocol targets on those end-uses.

Demand for each energy source is calculated using Energy Information Administration (EIA) data and forecasts for 1996, 2008, and 2012 for 27 common end-uses making up the four major sectors: residential, commercial, industrial, and transportation. Carbon emissions are then determined using carbon-emission coefficients for each fossil fuel. Finally, energy demand reduction requirements are calculated by applying the Kyoto Protocol target of a 7% reduction in carbon emissions from 1990 levels to the 2008 carbon emission levels for each end-use.

Based on EIA forecasts, by 2008, total carbon emissions from energy use by the 27 end-uses is calculated to be 1,721 million metric tons carbon-equivalent (MMTCE) compared to 1,464 MMTCE in 1996. Five end-uses — light duty vehicles (primarily automobiles, sport utility vehicles, small trucks, and vans), freight trucks, residential miscellaneous (small appliances and outdoor machinery), industrial machine drive, and miscellaneous commercial (communications and information equipment) — would comprise over 70% of the 1996-2008 increase in carbon emissions.

The Kyoto Protocol target would require average carbon emissions of 1,252 MMTCE from the 27 end-uses over the 2008-2012 period if it were applied uniformly to all sources of greenhouse gases. In this case, energy demand for each of the end-uses would have to decline by about 28.7% below the levels now forecast for 2008. Further, resultant energy demand for each of the end-uses would be about 20%, on average, below the actual 1996 values. Finally, on average, the required reductions from the current 2012 forecast would be about 31%.

Reductions of that magnitude would require substantial increases in energy efficiency, above those already forecast, and/or significant reductions in the services provided by a given end-use. For example, if the target were to be met solely by increases in efficiency, the average fuel economy of the light duty vehicle fleet would have to grow from the current forecast value of about 20.3 miles per gallon (mpg) to over 29 mpg by 2008. If the reduction were to be met solely by driving less, annual passenger car (passenger cars consume about 70% of the fuel used by light duty vehicles) travel would have to drop from the current forecast of 14,500 miles per car to about 10,300 miles per car. Such actions would be a substantial undertaking and consumers are likely to feel significant effects from any strategy that is used to try to meet the Kyoto Protocol targets.

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Introduction

Background

The potential for global climate change from the buildup of greenhouse gases in the Earth's atmosphere has elicited considerable concern by the world's nations.[1] A major source of that concern is the contribution to that buildup by greenhouse gases resulting from human activity. Historically the predominant greenhouse gas from human activity has been carbon dioxide (CO_2) although other gases have been gaining in importance in recent years. Nevertheless, CO_2 is expected to remain the largest single contributor to greenhouse gas buildup from human activity for at least the next 60 years.

The principal source of such CO_2 is energy use. It is a byproduct of combustion of fossil fuels. In 1996, the Department of Energy (DOE) estimated that the United States produced 1,462 million metric tons-carbon equivalent (MMTCE)[2] of CO_2 from the combustion of 85.2 quadrillion Btus (Quads) of fossil fuels.[3]

The growing concern about greenhouse gas-induced global climate change has prompted major international efforts to limit the buildup. The most recent of these was the December 1997 United Nations (Kyoto) Protocol on Global Climate Change, which established greenhouse gas reduction targets for the developed nations signatory to the accord.[4] That agreement, which the United States has signed but not ratified, would require the United States to achieve average annual carbon-equivalent emissions of six greenhouse gases over the period 2008-2012 that are 7% below specified baseline years. For CO_2, the baseline year is 1990. According to DOE, the United States produced 1,353 MMTCE in 1990 from energy use.

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[1]Congressional Research Service, *Global Climate Change*, by Wayne Morrissey and John Justus, CRS Issue Brief 89005 (updated regularly).

[2]One ton-carbon equivalent is equal to 3.67 tons of carbon dioxide.

[3]Energy Information Administration, Department of Energy, *Annual Energy Outlook, 1998: With Projections Through 2020*, DOE/EIA-0383(98) (December 1997), 100, 124.

[4]Congressional Research Service, *Global Climate Change Treaty: Summary of the Kyoto Protocol*, by Susan Fletcher, CRS Report 98-2, 22 December 1997.

There have been several analyses of the implications of meeting the reduction targets set by the Kyoto accord. Most recently, the Energy Information Administration (EIA) of DOE reported on the impacts on the U.S. energy markets and economy of those reductions.[5] In addition, a DOE study carried out by five of its national laboratories examined the potential for new energy supply and demand technologies to help meet those targets with a minimum of economic dislocation.[6] Those studies carried out detailed examinations of U.S. energy demand in analyzing the potential impacts of CO_2 emission reduction.

With some exceptions, however, the detail did not extend to the specific end-uses — such as motor vehicles or air conditioning — that consumers are familiar with. Although the Interlaboratory (called the 5-lab) study looked at specific end-use technologies, it did not provide data on end-use energy demand and CO_2 emissions for all major end-uses. While such information is not necessary to estimate potential economic impacts of CO_2 emission reduction, it can be helpful in gaining an understanding of the potential consequences of such actions at the consumer level.

Report Purpose and Format

This report presents estimates of actual and forecast energy demand for all of the common energy demand end-use categories for 1996, 2008, and 2012. It then calculates the CO_2 emissions for these estimates. With these values the reader should be able to see which, of the several ways energy is used in this country, are the major sources of CO_2 emissions. A similar report was prepared in 1991, which presented energy demand and CO_2 emissions estimates for 1988 and 2000.[7]

This report goes further than the previous report by presenting an analysis of the CO_2 emission reductions called for by the Kyoto accord. This analysis is based on a spreadsheet model that estimates the CO_2 emissions reductions for each of the end-use categories for both 2008 and 2012, and calculates the energy demand reductions needed to meet those emissions targets. In this way, the reader can see just how any of the common energy demand end-uses would be affected by reaching the targets. The report concludes with a discussion of implications of these reductions for representative end-uses.

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[5]Energy Information Administration, Department of Energy, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, SR/OIAF/98-03, (October 1998).

[6]Office of Energy Efficiency and Renewable Energy, Department of Energy, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*, prepared by the Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies.

[7]Congressional Research Service, *Energy Demand and Carbon Dioxide Production*, by Richard Rowberg, CRS Report 90-204, 11 February 1991.

Energy Demand by End-use Category

Background

The EIA divides U.S. energy demand into four sectors: industrial, residential, commercial, and transportation. Each sector is characterized by sources of energy supply and by specific end-uses. The sources of energy are the fossil fuels, renewables, and electricity. Electricity, of course, requires primary energy sources, namely fossil fuels, nuclear fuels, and renewables. End-uses are defined as specific functions or equipment that perform services for consumers such as cooling, heating, rail transport, electric motors, and lighting. Table 1 presents the energy sources and end uses considered in this report. There are 27 end-uses in all. The term in parentheses after each end use is a symbol used to denote the end-use in graphical representations to follow. The end-uses are not presented in any special order. Also, the energy sources in the right column are not meant to correspond to the end-uses in the left column. A given end-use usually requires more than one source of energy.

While most of the end-uses are self-explanatory, some need further explanation. The miscellaneous end-use in the residential sector includes motors and heating elements commonly found on gardening equipment, machine tools, and small appliances. Appliances in this sector include refrigeration, cooking, freezers, clothes washers and dryers, color televisions, and personnel computers. In the commercial sector, miscellaneous includes electronic office equipment, telecommunications, medical equipment, service station equipment, and manufacturing performed in commercial buildings.

Table 1. End-uses and Energy Sources
(By Sector)

End-uses	Energy Sources
Residential	
Space Heating (SHR) Water Heating (WHR) Appliances (ApR) Air Conditioning (ACR) Lighting (LR) Miscellaneous (MR)	Distillate Fuel Oil Liquid Petroleum Gas Natural Gas Coal Renewable Energy Electricity
Commercial	
Miscellaneous (MC) Lighting (LC) Air Conditioning (ACC) Space Heating (SHC) Water Heating (WHC) Cooking & Refrig (CRC)	Distillate Fuel Oil Residual Oil Liquid Petroleum Gas Motor Gasoline Natural Gas Renewable Energy Electricity
Industrial	
Direct Heat (DHI) Machine Drive (MDI) Steam (StI) Construction & Agri (CAI) Mining (MnI) Heat & Air Cond (HAI) Electrolysis (EI) Lighting (LI) Electric Gen (EGI)	Distillate Fuel Oil Liquid Petroleum Gas Residual Oil Motor Gasoline Natural Gas Coal Renewable Energy Electricity
Transportation	
Light Duty Vehicles (LDT) Freight Trucks (FTT) Air (ArT) Marine (MaT) Rail (RT) Pipeline (PT)	Distillate Fuel Oil Jet Fuel Motor Gasoline Residual Oil Liquid Petroleum Gas Natural Gas Renewable Energy Electricity

In the industrial sector, direct heat refers to manufacturing processes requiring the direct application of heat such as metal treating and chemical production. Machine drive refers primarily to the use of electric motors to control manufacturing processes. Steam is used in manufacturing primarily as a heat source for chemical and metallurgical processes, as a power source for metal-forming equipment, and to drive turbines. Electrolysis is an electro-chemical process used primarily in aluminum production.

In addition to those manufacturing processes, the industrial sector contains construction, agriculture, and mining. Each of these "subsectors" contains several end-uses, but lack of good data prevents an accurate disaggregation. Therefore, each is counted as a separate end-use. Finally, the industrial sector uses a significant quantity of petroleum fuels for products such as asphalt, liquified petroleum gases, petrochemical feedstocks, and lubricants. Most of the carbon in these nonenergy applications is not released as CO_2 emissions, and the nonenergy end-uses are not included in the carbon emission analysis to follow.[8]

In the transportation sector, light duty vehicles include all vehicles weighing less than 8,500 pounds. These include automobiles, minivans, sport utility vehicles, larger passenger vans, and small trucks. Freight trucks include all commercial and freight trucks weighing over 8,500 pounds.

In each sector, electricity is given as one of the energy sources. Electricity, of course, requires primary energy sources for its generation. These sources are distillate and residual fuel oil, natural gas, coal, and nuclear and renewable energy. In the calculations to follow, it is assumed that for a given year, the mix of energy sources to generate electricity is the same regardless of which sector uses the electricity. The mix will change over time, however, and those changes are incorporated.

Analytical Method

Energy demand in the United States for 1996 was adopted for the baseline because that is the last year for which complete data are available for all sectors. For the residential and commercial sectors, data for end-use energy demand by fuel are directly available from the EIA.[9] Consolidation of some of the end-uses provided by EIA was made by combining several household appliances in a category called residential appliances, and combining all commercial categories labeled other uses with commercial office equipment in a category called commercial miscellaneous. These new categories are described above.

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[8]A small fraction of the carbon — about 20% — of these nonenergy uses, according to the EIA, does end up as CO_2 in the atmosphere. The effect of this contribution will be discussed but will not be included in the detailed results because it is very small. See: Energy Information Administration, Department of Energy, *Emissions of Greenhouse Gases in the United States, 1996,* DOE/EIA-0573(96), (October 1997), 70.

[9]Energy Information Administration, *Annual Energy Outlook 1998*, 106-109.

For the transportation sector, the EIA provides separate reporting of total energy use by the various categories and by energy source.[10] As a result, estimates have to be made of how much of a given energy source are used by any end-use. This can be done by noting that there is a predominate energy source for a given end-use and that most of the categories will use no more than two different kinds of energy sources. For example, light duty vehicles will use primarily gasoline with a small amount of distillate, air transport will use all of the jet fuel and a small amount of gasoline, and rail is the primary user of electricity but also uses residual fuel oil. By reconciling the total energy demand for each end-use with that for each energy source, an accurate picture of energy demand by energy source for each end-use can be obtained.

For the industrial sector, the calculation is more complex. The sector is made up of four subsectors: manufacturing, construction, agriculture, and mining. Detailed energy use data by end-use exist only for the manufacturing sector. The EIA publishes a survey of manufacturing energy use every three years, the most recent for 1994. The report provides data on the major end-uses by energy source.[11] A complication arises in that a large fraction of the totals reported by end-use and by energy source are not specified. By going to the individual industry groups much of those unspecified values can be estimated from noting the types of processes used by those industries. For example, unspecified fuel in the paper and paper products industry is likely to be wood used to produce steam. In petroleum refining, the unspecified fuel is likely to be still gas, a product of the refining process, used for direct heat and steam. Once energy demand by end-use and energy source is determined for 1994, the 1996 value can be estimated by adjusting each energy source by the 1994-1996 growth rate. That method assumes that there is no significant shift of the type of energy source used by the end-uses over that period.

For mining, the census of mineral industries published by the U.S. Census Bureau of the Department of Commerce provides data on energy use for 1992 by energy source for the entire mining industry.[12] No data are provided by end-use. For that reason, the entire mining industry is included as a separate end-use. To obtain values for 1996, the value of each energy source is adjusted by its the 1992-1996 growth rate. For construction and agriculture, no energy use data are available. Total energy demand by energy source for the entire industrial sector, however, is available.[13] By subtracting total energy demand by energy source for the other two subsectors from the industry total, and considering construction and agriculture as one end-use, its energy demand can be estimated as the residual.

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[10]Ibid. 102, 111.

[11]Energy Information Administration, Department of Energy, *Manufacturing Consumption of Energy, 1994,* DOE/EIA-0512(94), (December 1997), 114.

[12]U.S. Census Bureau, Department of Commerce, *1992 Census of Mineral Industries: Fuels and Electric Energy Consumed*, MIC92-S-2. See: [http://www.census.gov/mcd/minecen/download/nc92feec.txt].

[13]Energy Information Administration, *Annual Energy Outlook 1998*, 101.

For the years 2008 and 2012, the EIA forecasts are used to estimate energy demand by end-use and energy source.[14] The *Annual Energy Outlook, 1998* provides forecasts for the years 2005, 2010, and 2015, among others.[15] To obtain forecast estimates for 2008 and 2012, therefore, it is first necessary to determine the forecast for energy demand by end-use for 2010.[16] Energy demand forecasts for the residential and commercial sector end-uses are obtained directly for 2010 just as described above for 1996. Similarly, estimated energy demand by end-use for the transportation sector for 2010 can be obtained from the EIA data using the same methods as for 1996.

For industry, a different method must be used because there are no forecasts of manufacturing energy demand by end-use. The EIA, however, does provide forecasts of energy demand by energy source for the entire industrial sector. By adjusting each energy source for a given end-use by the 1996-2010 growth rate for that energy source for the entire sector, an estimate of the energy demand for that end-use for 2010 can be made. This method assumes that the relative mix of energy sources for a given end-use does not change significantly over that period. That is a valid assumption because a major energy-source mix change in one end-use would require an equal and opposite change in one or more of the remaining end-uses in order to keep the totals for the sector unchanged. Such actions are quite unlikely, particularly over a 14-year period.

Once the forecasts for 2010 are obtained, they can be modified to provide estimates of the forecasts for 2008 and 2012. This modification is performed by first calculating the annual growth rate between 2005-2010 and 2010-2015 for each energy source by sector. The data for these calculations are obtained from the EIA *Annual Energy Outlook, 1998.* With those growth rates, it is a straightforward matter to adjust each of the energy sources for each of the end-uses by the appropriate annual growth rate. This method assumes that the 2005-2010 and 2010-2015 growth rates for a given energy source are the same for all end-uses in a sector. In the cases where that assumption can be checked — the residential and commercial sectors — it is not strictly correct. The error introduced for those two sectors, however, will be small because the growth rates themselves are small, 1% per year and less. For the other two sectors, it is unavoidable, given the data available, but also quite small.

Results

The results of those calculations are shown in Figure 1 (on next page) for all 27 end-uses. They are arranged in descending order of energy demand forecast in 2012. The results present primary energy demand for each end-use; waste heat produced in

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[14]For this report, the EIA reference case forecast is used. That forecast is based on a macroeconomic model that calculates a series of indicators that are used to drive the energy demand model. Among the indicators for the reference case are an annual growth of real GNP of 3.0% per year between 1996 and 2020, and a decline in total energy intensity (1000 Btu/1992 dollar of GDP) of 0.9% per year over the same period. See, Energy Information Administration, *Annual Energy Outlook, 1998,* 125.

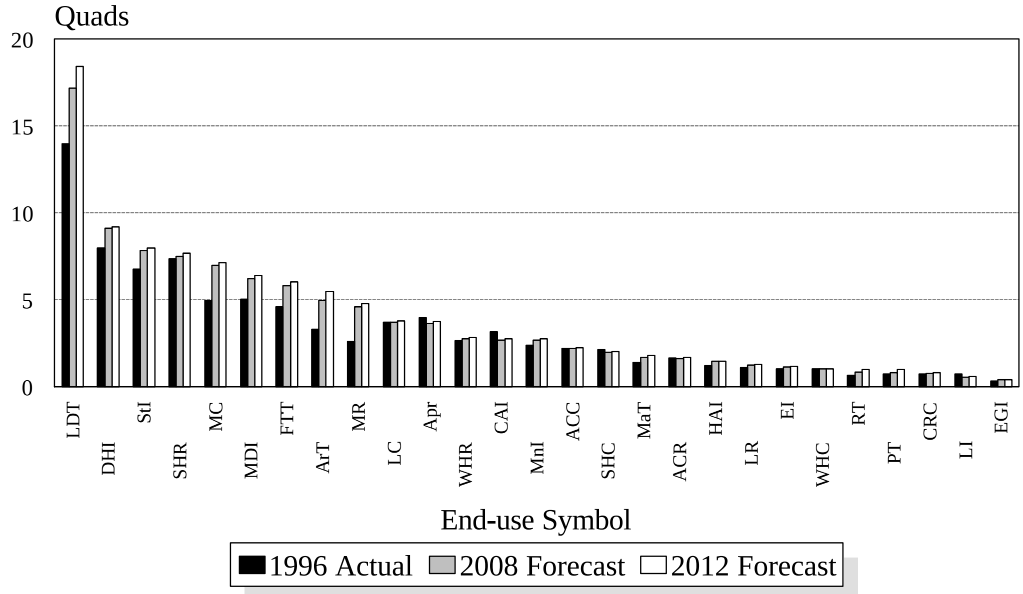
[15]Energy Information Administration, *Annual Energy Outlook, 1998*, 101, 106-111.

[16]In all cases the EIA reference case forecast is used.

the generation of electricity is assigned to the electricity total for each end-use.[17] Tables presenting the actual data are in the Appendix to this report.

Total energy demand represented by all 27 end-uses in 1996 — 87.5 Quads — is nearly equal to the value of total energy demand reported by EIA — 88.1 Quads — indicating that these 27 end-uses virtually capture the full range of U.S. energy demand. For 1996, EIA also reports that non-energy uses, as discussed above, consumed 5.95 Quads of fossil fuels. For 2008, energy demand for the 27 end-uses is 101.5 Quads and for 2012 it is 105.7 Quads. The EIA estimates for total energy demand including nonenergy uses of fossil fuels for those two years are 109.6 Quads and 113.6 Quads, respectively. These values would indicate that nonenergy use for 2008 and 2012 is 8.1 Quads and 7.9 Quads respectively. Based on extrapolation of

Figure 1. **Energy Demand by End-use: 1996, 2008, 2012**



past trends those values are reasonable, although it is unlikely that nonenergy, fossil fuel use would decline from 2008 to 2012. The value for 2008 is probably a little high, while that for 2012 somewhat low. This means that the estimates for energy demand determined from summing the end-uses is somewhat low for 2008 and somewhat high for 2012. The discrepancy is small, however, and very likely to be within the EIA forecast errors.

Of the individual end-uses, the one with the largest energy demand is light duty vehicles. It is nearly twice the size of the next largest end-use, direct heat for industrial processes. Furthermore, its energy demand is forecast to grow significantly from 1996

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[17] About two-thirds of the energy used to produce electricity is lost as waste heat. Thus one Quad of electric energy delivered to consumers represents about three Quads of primary energy used. Some of the waste heat is used for low-level heat — e.g., space heat — in industry and commercial buildings, and, as such, replaces other energy sources. This secondary use of "waste heat" is particularly prevalent with electricity generated on-site by industry. This process is called cogeneration.

to 2012 primarily as a result of a substantial increase in vehicle miles traveled.[18] Other end-uses that are expected to grow sharply between 1996 and 2012 are the miscellaneous categories in both the residential and commercial sectors. A rapid expansion in office electronic and telecommunication equipment, and in a variety of small residential appliances and outdoor heating equipment and motors is expected to be responsible for that growth. Electricity is by far the dominant energy source for those miscellaneous end-uses. Those three end-uses — light duty vehicles and the two miscellaneous categories — constitute 48% of the projected growth in energy demand between 1996 and 2012.

CO_2 Emissions

Analytical Method

The first step in estimating CO_2 emissions is to determine the carbon emission coefficients for the fossil fuels used as energy sources. Each fossil fuel has a characteristic CO_2 production rate, or emission coefficient, determined by the chemistry of that fuel. That rate is the amount of CO_2 that will be produced upon complete combustion of a specific quantity of fuel. Those rates are given in Table 2 in terms of millions of metric tons of carbon (MMTC) produced per Quad of energy used.[19] [20] The coefficients for a given fuel can change from year-to-year depending on the quality of the fuel produced that year. The changes will be small, however, and the EIA has reported no changes for petroleum products and natural gas over the period 1986 to 1996.[21] There have been slight changes for coal, but they are very small and possible future changes will not be considered in this report. Therefore, the carbon emission coefficients for fossil fuels are assumed to remain constant over the period covered by this report, 1996 to 2012.

Table 2. Carbon Emission Coefficients
(Millions of Metric Tons per Quad)

Source	1996	2010
Gasoline	19.38	19.38
LPG	16.99	16.99
Jet Fuel	19.33	19.33
Distillate	19.95	19.95
Residual	21.49	21.49
Coal - Res/Com	26.00	26.00
Coal - IND	25.63	25.63
Natural Gas	14.47	14.47
Electricity	16.04	16.50

[18]Energy Information Administration, *Annual Energy Outlook, 1998,* 111. EIA forecasts only a small increase in light duty vehicle energy efficiency over that period: 20.2 mpg in 1996 to 20.3 mpg in 2010.

[19]Energy Information Administration, *Emissions of Greenhouse Gases,* 100.

[20]These coefficients are presented in terms of the amount of carbon produced. To calculate the amount of CO_2 produced it is necessary to multiply the coefficient by 3.67, the ratio of the molecular weight of CO_2 to that of carbon.

[21]Energy Information Administration, *Emissions of Greenhouse Gases,* 100.

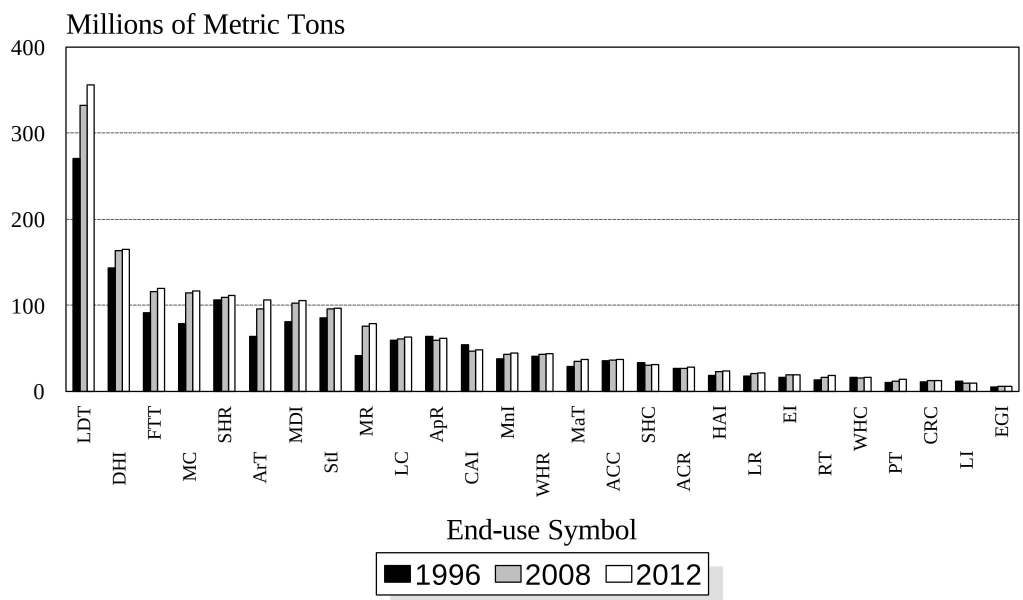
For electricity, the coefficient is calculated from the coefficients of the fossil fuels used in the generation mix, weighted by their contribution to that mix. This mix will change over time. Using EIA forecasts for the generation mix in 2010, the carbon emission coefficient for electricity for that year can be calculated. Note that the change between 1996 and 2010 is small. While the value for 2008 and 2012 can be estimated by using the 2005-2010 and 2010-2015 fossil fuel growth rates given by the EIA, the changes from 2010 are likely to be insignificant. Therefore, the 2010 value is used in calculating carbon emissions for 2008 and 2012.

Once the carbon emission coefficients are calculated, it is relatively straightforward to calculate the total amount of carbon emitted by each end-use in the selected year. For each end-use, the quantity of energy from a each energy source is multiplied by the appropriate carbon emission coefficient and the results are summed. Using those coefficients, of course, will yield carbon emissions not CO_2 emissions. Although it is simple to convert to CO_2 emissions (see footnote 19), this will not be done in order to be consistent with the way the EIA presents emissions data.

Results

The results of this calculation are given in Figure 2. The detailed data are provided in tables in the Appendix. The data in the figure are displayed by order of end-use emission rankings forecast for 2012. Total carbon emissions in 1996, calculated by aggregating end-uses, were 1,464 million metric tons carbon equivalent (MMTCE). The EIA reports that total 1996 carbon emissions, including those from non-energy use of fossil fuel, were 1,463 MMTCE.[22] The CRS estimate might be slightly high because no emissions from non-energy uses of fossil fuels were included. As noted above, about 20% of the carbon in those fuels was released to the

Figure 2. Carbon Emissions by End-use: 1996, 2008, 2012



[22]Energy Information Administration, *Annual Energy Outlook, 1998*, 124.

atmosphere. This would amount to carbon emissions of about 15 to 20 MMTCE. Nevertheless, the value calculated here is quite close to the EIA total indicating that the end-use structure is valid.

For 2008 and 2012, aggregation of the end-use carbon emissions yields totals of 1,721 and 1,795 MMTCE respectively. The EIA forecasts for these two years are 1,757 and 1,837 MMTCE respectively. Considering the effect of non-energy uses of fossil fuels as discussed in the previous paragraph, the results obtained from aggregating end-use emissions appear quite consistent with the EIA forecasts.

The largest contributor to carbon emissions was, and is expected to continue to be, light duty vehicles. That end-use is forecast to contribute almost twice as much carbon as the next highest end-use, direct heat for industry. These observations, of course, are consistent with those reported above in the discussion of energy demand. There is not, however, a direct correlation between total energy demand and carbon emissions. Rather the energy source mix can play an important role in determining the relationship between energy demand ranking and carbon emission ranking. In particular, industrial steam and residential space heat rank higher on the energy demand scale than the carbon emission scale because both include a significant amount of biomass — wood combustion — in their energy source mix. Wood combustion does not produce any net production of CO_2 as long as the wood used for energy production was not previously counted as a sink for CO_2.[23]

Nevertheless, there are a number of similarities in the two tables. Light duty vehicles, and residential and commercial miscellaneous are projected to have the largest increases in carbon emission between 1996 and 2008, and 1996 and 2012. Other end-uses that indicate a large increase are freight trucks, air transport, and industrial machine drive. These five end-uses make up 70% of the forecast increase of total carbon emissions from energy use between 1996 and 2012.

For some end-uses, carbon emissions are forecast to change very little and, in some cases, decline. All of the end-uses in the residential and commercial sector, except the miscellaneous categories, are expected to be nearly the same in 2012 as in 1996. This level behavior is due primarily to projected increases in energy efficiencies for those end-uses. Most industry and transportation end-uses, however, are forecast for significant growth. On average, the rate of forecast efficiency gains for the end-uses in those sectors does not match their projected energy-demand growth resulting from continued economic growth.

[23]During tree growth, carbon is sequestered as a result of the photosynthesis process whereby plants consume CO_2 and give off oxygen. Because this growth takes place within years of the time when the combustion of the wood takes place, there is no net production of CO_2 over the time frame of concern for possible greenhouse gas induced climate change.

Emission Reductions

Kyoto Protocol Targets

In 1997, the United States joined with more than 160 nations to negotiate greenhouse gas emission reductions targets. The result was the Kyoto Protocol that established such targets for the Annex I countries.[24] Those countries are among the ones that have ratified the 1992 United Nations Framework Convention on Climate Change. According to the Protocol, the United States is to reduce those emissions to a level 7% below 1990 levels. There are six greenhouse gases covered in the Protocol and the targets are based on the carbon equivalent of each gas. These gases are CO_2, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. For last the three of the gases, there is an option that 1995 can be adopted as the base year.[25]

In 1990, total emissions of the six greenhouse gases was 1,618 MMTCE .[26] If the 1995 base year is adopted for the three gases, the total becomes 1,629 MMTCE. Of the total, 1,374 MMTCE is CO_2, of which 1,346 MMTCE comes from fossil fuel combustion for energy use. The nonenergy CO_2 is from certain industrial processes, primarily cement production and limestone consumption.

There are considerable uncertainties involved in calculating the targets and reduction quantities required.[27] One of the principal ones is how the reduction will be allocated among the various gases. It might be possible to reduce some gases well beyond the 7% target allowing smaller reductions in others. In addition, the Protocol allows countries to trade emissions credits.[28] That process could allow a loosening of the target level for the United States.

One of the purposes of this report is to show what would happen to energy demand levels for the common end-uses if the targets were applied uniformly. Therefore, to determine the required carbon emission targets, the 7% reduction will be taken from carbon emissions resulting from energy production in 1990. This target level is 1,252 MMTCE. One other case has been considered, that of a 3% reduction from the 1990 levels. This reduction level was estimated by the U.S. Department of State and cited by the Council of Economic Advisors as possible given the flexibility

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[24]Congressional Research Service, *Global Climate Change Treaty: Summary of the Kyoto Protocol*; and Congressional Research Service, *Global Climate Change*.

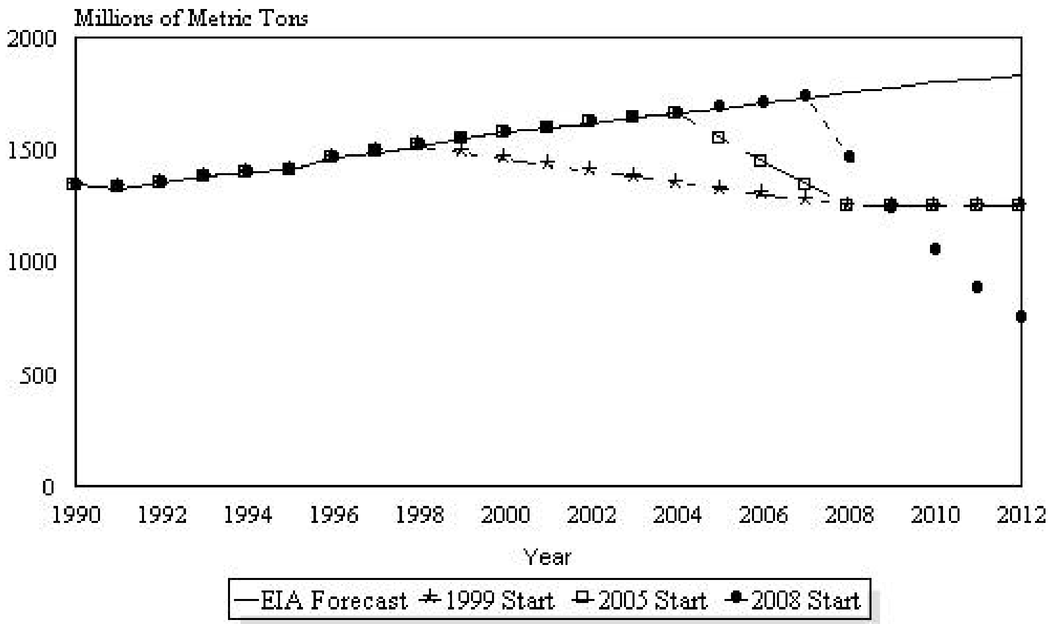
[25]Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. energy Markets and Economic Activity*, xi.

[26]Energy Information Administration, *Emissions of Greenhouse Gases,* x, 18.

[27]For an extensive discussion of the uncertainties, see, Congressional Research Service, *Global Climate Change: Reducing Greenhouse Gases — How Much from What Baseline?* by Larry Parker and John Blodgett, CRS Report 98-235 ENR, 11 March 1998.

[28]Congressional Research Service, *Global Climate Change*.

inherent in the Protocol.[29] This target level is 1,306 MMTCE. The difference between the two target levels is small, however, and will not significantly affect the implications



of reaching these levels for any of the end-uses.

In addition to determining the target level, there is also the question of when the reductions would start. The Protocol states that the average emissions over the five-year period must equal the target. Therefore, if the 7% reduction is met in 2008, emissions can remain flat throughout the period. If no reduction has taken place by 2008, the reduction necessary by 2012 must be substantially greater. This behavior is shown in Figure 3 which compares different trajectories to the target level. In the extreme case of waiting until 2008 to begin, and assuming a constant percentage decline each subsequent year, the 2012 target level becomes 756 MMTCE, 59% below the current EIA forecast for that year. Starting in 2005, the case adopted by the EIA assessment,[30] and assuming a constant percentage decline to the target of 1,252 MMTCE in 2008, would require a 6.9% per year rate of decline. Starting in 1999 to the same target, would require a 1.9% per year decline.

It is clear that the degree of difficulty in reaching the target levels would increase dramatically as the year in which the reductions begins approaches 2008. For the purposes of this paper, it is assumed that reduction would begin some time before 2008 and reach the 7% (or 3%) level by 2008 so that carbon emissions are constant over the 2008-2012 period.

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[29]Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, xii.

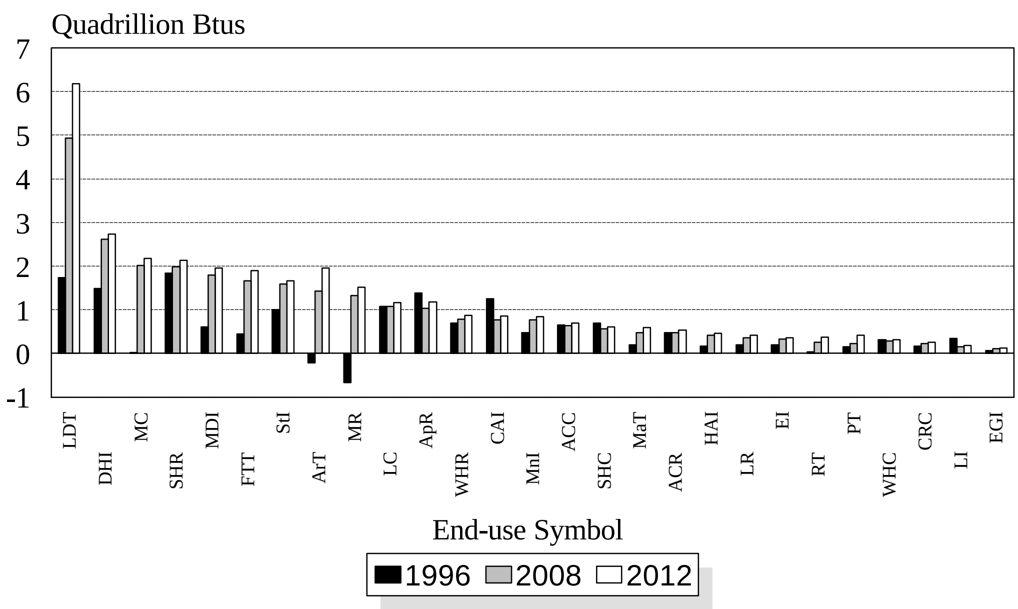
[30]Ibid.

Reduction Levels

To estimate the consequences of reaching the reduction targets of 7% below 1990 carbon emissions on end-use energy demand in 2008, it is assumed that the reductions are applied uniformly to all the end-uses. The 2008 carbon emissions of each end-use are multiplied by the ratio of the target emissions level to the total carbon emissions from all energy use in 2008 as forecast by the EIA.[31] The results are the allowed carbon emissions for that end-use to meet the targets set by the Kyoto Protocol. Once those target emission levels are determined, the energy demand levels that would be required to produce those target emission levels can be calculated. First, the average carbon emissions coefficient for each end-use is calculated using the 2008 values.[32] Then, the target emission levels for a given end-use are divided by its average carbon emission coefficient, giving the target energy demand level. Finally, the difference between the forecast level and the target level gives the required energy demand reduction needed to meet the Kyoto Protocol targets for each end-use.

The results of this calculation are shown in Figure 4 for 2008. The detailed data are in the Appendix. Because carbon emissions would have to remain constant at 1,252 MMTCE over that period to meet the Kyoto Protocol requirements, energy demand for each end-use would also have to remain constant as long as each end-use is sharing the reduction proportionately. The higher energy demand forecasts for 2012 as shown above mean that the reductions for each end-use in 2012 would be correspondingly higher. These reductions are also shown in Figure 4 and the detailed data are shown in the Appendix.

Figure 4. End-use Energy Demand Reduction Requirements



[31] The EIA forecast is used instead of the aggregate from all of the end-uses calculated by CRS because the former accounts for the nonenergy contribution as described above, and such contributions are included in the target level. Therefore, both parts of the ratio will be comparable.

[32] This is just the ratio of total carbon emissions for that end-use to the total energy demand for that end-use from all energy sources.

Figure 4 also presents the energy demand reductions from 1996 actual levels that would result from meeting the Kyoto Protocol requirements. A negative value means that the target energy demand level in the 2008-2012 period would be higher than the 1996 actual level. Only two end-uses show such behavior, residential miscellaneous and air transport. For both, EIA forecasts that energy demand is expected to grow well above the average of all end-uses. Other end-uses that are forecast to grow rapidly, such as commercial miscellaneous and light duty vehicles, show relatively small reductions from the 1996 actual levels. For nearly all of the end-uses, however, the target levels for 2008-2012 would be significantly below the 1996 recorded energy demand. Indeed, some end-uses show larger reductions from 1996 levels than from the 2008/2012 forecasts. Those are primarily in the residential and commercial sectors and are end-uses where substantial efficiency gains are expected in coming years such as residential appliances and commercial space heating. In percentage terms, the reductions that would be required from 1996 actual levels range from about a negative 25% to a positive 49% with an average of about a positive 20%.

Under the method used in this report to apportion the reductions that would be required by the Kyoto Protocol, each end-use contributes the same percentage reduction in carbon emissions and energy demand for 2008. For that year, energy demand would be reduced by about 28.7%. Because the energy demand target level remains fixed from 2008 to 2012 but demand growth for each end-use is forecast to grow at different rates over that period, the percentage reduction in energy demand for 2012 would not be the same for each end-use. The percentage reductions for 2012 in end-use energy demand would range from about 29% to 41% with most around 31%.

Discussion

Implications. Reaching the Kyoto Protocol target for carbon emissions from energy use would result in energy demand in the year 2008 of about 70.2 Quads.[33] This would be about 28.3 Quads below the amount the EIA now forecasts for total energy use in 2008 and about 14.8 Quads below the amount used in 1996. It would be the lowest total U.S. energy demand since 1988. Taken from the 1996 level, to reach that target by 2008 would require a decline of about 1.6% per year. If actions do not begin until 2005, as assumed in the EIA study on impacts of the Kyoto Protocol, energy demand would have to decline by about 10.5% per year to reach the target level. The longest stretch of declining energy demand in the United States since 1949 occurred from 1979 to 1983 following the second Arab oil embargo and oil price spike. Over that period, total energy demand dropped by 10.6% or about 2.8% per year for the four-year period. While that rate is considerably greater than 1.6% per year, it is much less than 10.5% per year, and the total percentage drop that took place is about one-half that which would be required to meet the 2008 Kyoto Protocol target from 1996.

In discussing these results, three examples are considered: light duty vehicles, residential space heating, and industrial direct heating. Those are large energy demand categories in three different sectors. The assessment will consider changes in energy

[33]In addition, there would be about 7.5 Quads of fossil fuel use for nonenergy purposes and about 3.6 Quads of biomass making a total of about 81.3 Quads.

efficiency needed to meet the targets as well as consequences of reducing energy demand without any efficiency gains. Finally, a review of historical energy demand for each of the three end-uses will be made to see whether there are precedents for reductions called for to meet the Kyoto Protocol targets.

Light Duty Vehicles. The end-use with the largest energy demand is light duty vehicles. Meeting the Kyoto target would require a decline in energy use by these vehicles of 4.9 Quads from the level now forecast by the EIA for 2008 and about 1.7 Quads from the amount used in 1996. This would amount to a drop of about 880,000 barrels a day of gasoline consumption. To achieve that decline by 2008 would require an increase of the average fuel efficiency of the entire light duty vehicle fleet from 20.3 miles per gallon (mpg) to 23.3 mpg assuming *no* increase in vehicle miles traveled (VMT) between 1996 and 2008. If the EIA forecast of VMT for 2008 is met, fuel efficiency would have to reach 29.6 mpg, an annual rate of increase of 3.2%. Currently, the EIA forecasts that the light duty vehicle fleet will operate at 20.3 mpg in 2008.

While historical fuel efficiency data for light duty vehicles as a group do not exist, data for passenger cars, which constitutes about 60% of all light duty vehicles, show that fuel efficiency grew from 14.6 mpg in 1979 to 21.2 mpg in 1991. The annual rate of increase for that 12 period was 3.2%.[34] For all motor vehicles, however, the increase was considerably less over that period, 2.6% per year. Because the latter includes freight trucks, the actual increase for light duty vehicles was somewhere in between these two rates. Since 1989, however, fuel efficiency for light duty vehicles has increased from 18.5 mpg to 20.2 mpg. This slow growth in fuel efficiency plus the forecast that such growth will continue to be slow for the next two decades at least, indicates that most of the effects of the fuel economy standards established in the late 1970s might already have been achieved. Therefore, to achieve the growth in fuel economy required to meet the Kyoto target, would require a return to rapid growth in new vehicle fuel economy.

It should be noted, however, that since the mid-1980s, there has been little increase in the Corporate Average Fuel Economy (CAFE) standards for new automobiles or for light trucks such as sport utility vehicles, vans, and pickup trucks. The CAFE standards for new automobiles has remained at 27.5 mpg since 1985, and the standard for new light trucks has only increased from 20.5 mpg in 1987 to 20.7 mpg in 1996.[35] Furthermore, over the same period the automobile portion of the light duty vehicle fleet has been decreasing. In 1979, over 79% of all vehicle miles traveled by light duty vehicles were accounted for by automobiles. In 1996, that percentage had dropped to just over 64%.[36] The remainder of those miles were accounted for by

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[34]Energy Information Administration, Department of Energy, *Annual Energy Review 1997*, DOE/EIA-0384(97) (July 1997), 53.

[35]National Highway Transportation Safety Administration, Department of Transportation, *Automobile Fuel Economy Program: Twenty-second Annual Report to Congress, Calender Year 1997*, 3. See; [http/www.nhtsa.gov/cars/problems/studies/fuelecon/index.html].

[36]Oak Ridge National Laboratory, Department of Energy, *Transportation Energy Data Book: Edition 18*, ORNL-6941 (1998), 5-5. The report can also be found on

light trucks, which are less fuel efficient than automobiles. In 1996, the value for all automobiles was 21.5 mpg and for all light trucks was 17.3 mpg.[37]

If no efficiency gains were to take place, a substantial decline in VMT would be necessary. At a constant 20.2 mpg, vehicle miles traveled would have to decline about 12.4% from the 1996 actual level and about 28.8% from the level forecast for 2008. In terms of automobiles which make up about 72% of the VMT, this reduction would force annual miles traveled per automobile to drop to about 10,300 compared to the 1996 level of about 11,700 miles.[38] If miles traveled per automobile per year increased at the same rate as VMT according to the EIA forecast, the value in 2008 is now projected to be about 14,500 miles. Therefore, the VMT level required to meet the Kyoto Protocol target without any efficiency gains would be substantially lower.

Residential Space Heating. To meet the Kyoto targets for residential space heating energy demand, a decline would be required of 1.8 Quads, or 27.6%, from the 1996 level and about 2 Quads, or 28.7%, from the level now forecast by EIA for 2008. The small difference between the 1996 and 2008 reductions is a result of the continued efficiencies that the EIA forecasts will be forthcoming for residential space heating.

To achieve those reductions would require large increases in the efficiencies of residential building shell and/or heating systems, a substantial reduction in the temperature levels maintained in a typical house, or some combination of both. For example, if a typical residential building had an average building thermal barrier rated at R = 16, it would have to increase to R = 22 to reduce its space heating energy requirements for heating by 27.6%. It could also install new heating equipment that operated at a higher efficiency. To achieve the necessary fuel reduction, an efficiency gain of over 37% would be needed. For example, a furnace operating at 60% efficiency would need to be replaced by one operating at about 82%. Finally, if neither of these two efficiency improvements were possible, that residential building would need to decrease its average indoor temperature. For example, if the building's normal indoor temperature was 75 degrees, and the outdoor temperature averaged 40 degrees, the indoor temperature would have to be lowered to about 65 degrees to reduce its heating requirements in line with the Kyoto target.

A change in residential space heating energy demand of this magnitude has occurred before, from 1978 to 1980. The large increase in energy prices in the late 1970s drove the demand for space heating energy down by 22%, after correcting for changes in heat load, over that two-year period.[39] After that decline, however, residential space heating energy demand has stayed nearly constant, increasing by less than 10% between 1980 and 1996 after correcting for changing heating requirements.

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[36](...continued)
[http://www-cta.ornl.gov/data/tedb18/Index.html].

[37]Ibid., 2-16.

[38]Ibid., 5-6, 5-8.

[39]Heat load is measured in terms of heating degree-days. Energy Information Administration, *Annual Energy Review 1997,* 55, 23.

That behavior is due primarily to increasing building and heating system efficiencies, which have kept pace with housing stock growth and declining real energy prices.

DOE has assumed that those efficiency increases will continue in order to compensate for future housing stock growth. DOE forecasts that space heating demand per household will decline by 25% between 1996 and 2020.[40] Therefore, the reduction in space heating energy demand per household needed to meet the Kyoto Protocol levels, estimated at about 27% as described above, would have to come on top of the gains already forecast by DOE.

Industrial Direct Heat. This end-use is used for a variety of manufacturing processes. It is used principally for primary metal production such as in steel mill blast furnaces, to drive chemical reactions in chemical plants and petroleum refining, for glass and clay product manufacturing, and in food processing. To meet the Kyoto Protocol levels, industrial direct heat use would have to decline by about 1.5 Quads, or 18.7%, from the 1996 level, and 2.6 Quads, or 28.7%, from the forecast 2008 level. The EIA expects industrial direct heat energy demand to grow about 14.7% from now to 2008, because of continued growth in the manufacturing sector. By 2010, the EIA forecasts that manufacturing output will grow by about 42.5%.[41] The difference between the two growth rates is, in part, a result of expected increases in industrial process efficiency for those processes involving direct heat. In addition, manufacturing output in industries that use little or no direct heat are expected to grow faster than those that use a great deal.

To meet the Kyoto Protocol levels for industrial direct heat use, manufacturers would have to increase the efficiency of process heat equipment, increase process productivity for those goods requiring direct heat, reduce output, or undertake some combination of the three steps. An average heater efficiency increase of 23% would be required to reduce 1996 direct heat energy demand to the Kyoto target level. To maintain that level to 2008, given the current EIA forecast, would require a total heater efficiency increase of over 56% if that was the only action taken. That increase would have to come on top of efficiency increases already forecast by EIA.

To see the effect of meeting the Kyoto Protocol by reducing production, consider petroleum refining. In 1996, the United States produced about 17 million barrels per day (MMBD) of refined products. If the U.S. petroleum refining industry had to reduce its direct heat energy use to contribute its share in meeting the Kyoto protocol level, production would have to decline by about 18% or about 3 MMBD. In 2008, the EIA forecasts that U.S. refineries will produce about 19.5 MMBD.[42] In order to meet the Kyoto protocol by reducing production, U.S. refinery output would have to drop by about 5.5 MMBD to a total of 14 MMBD. Similar analysis could be carried out for other manufacturing areas requiring direct heat in their manufacturing process.

No historical data exist specifically on direct heat energy demand so it is not possible to compare, directly, the requirements of the Kyoto Protocol, as discussed in

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[40]Energy Information Administration, *Annual Energy Outlook, 1998,* 41.

[41]Ibid., 125.

[42]Ibid., 116.

the preceding paragraph, with past trends. It is possible, however, to determine industrial energy intensity by calculating the ratio of industrial energy demand to industrial output given in dollars.[43] From 1977 to 1989, industrial energy intensity declined by over 30%. The decline in industrial direct heat energy intensity needed to meet the Kyoto Protocol from the 1996 level is about 18%. If one assumes that total industrial energy intensity and direct energy intensity track, then it would seem that meeting the Kyoto protocol requirements is reasonable based on historical precedent. It should be noted, however, that total industrial energy intensity stopped its decline in 1989 and has risen slightly — about 5% — between 1989 and 1996. Furthermore, the 18% decline required by the Kyoto Protocol would have to come on top of efficiency gains already forecast by EIA. It projects a decline of 17% in industrial energy intensity between 1996 and 2010.[44] Again, assuming direct heat energy intensity and total energy intensity for industry growth (or decline) at the same rate,[45] the total decline in energy intensity required to meet the Kyoto requirements while allowing industrial output to grow to levels now forecast by EIA to 2008 would be over 40%. This is well beyond any historical changes.

As for reducing output, the question is whether consumers can accommodate less production, not whether industry can produce less because of lower energy demand. In the case of oil refinery production, from 1978 to 1983, oil products supplied in the United States declined by 3.6 MMBD. This exceeds the decline from 1996 supply needed for oil refineries to meet the Kyoto Protocol if they were to choose the lower production path. Accommodation to that production decline between 1978 and 1983 was a complicated combination of fuel switching, reduced economic output and increased energy efficiency. Since 1983, however, the volume of oil products supplied has increased steadily to a current level near the 1978 peak. Furthermore, the EIA forecasts continued increases as noted above. The reduction that would be needed for oil refinery output to meet the Kyoto protocol from the 2008 forecast level — 5.5 MMBD — is considerably greater than past levels.

Concluding Comments. The analysis presented here provides a detailed view of how energy is used in the United States. It also provides a clear picture of the contribution these end-uses make to the buildup of carbon dioxide in the earth's atmosphere. Finally, it presents a way to analyze the contributions each end-use would make to any strategy to reduce CO_2 emissions, and the implications of those strategies in terms of particular end-uses.

Obviously, end-use disaggregation could continue beyond that given in this report. For example different types of light vehicles and different types of industrial direct heat processes exist. In particular, it was seen above that the contribution of

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[43]Council of Economic Advisors, Office of the President, *Economic Report of the President*, (February 1998), 297.

[44]Energy Information Administration, *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, 53.

[45]To the degree that future gains in industrial output are disproportionately accounted for by less energy-intensive industry, this assumption becomes less valid. Nevertheless, the decline in direct heat energy intensity to meet the Kyoto Protocol is still likely to be substantial as long as total industrial output is not to suffer.

light trucks — sport utility vehicles, vans, etc. — to the light utility vehicle fleet is growing. Data to carry out finer breakdowns, however, exist in only a few cases, and further disaggregation would be less and less precise. While current and historical data for different components of the light duty vehicle fleet exist, projections of that mix are lacking. Furthermore, it is not clear that, with the possible exception of light duty vehicles and the commercial and residential miscellaneous categories, more disaggregation would add much to understanding how energy is used or to the analysis of the implications of reduced energy demand.

It is clear from the examples given above that the reduction in energy demand needed to reach the Kyoto Protocol targets under the assumptions made in this report would be substantially greater than previous changes in U.S. energy demand. While reductions required from 1996 levels, for the three examples considered above, appear to be comparable to those taking place in the past, when growth in energy demand that is expected between now and 2008 or 2012 is factored in, the changes required are nearly all unprecedented. Similar observations would hold for other end-uses because of the underlying sector growth now forecast.

Achieving the energy demand reductions by increases in efficiency to maintain the growth in products and services supplied by each end-use appears to require substantial gains in equipment efficiency. While for the three cases examined the gains do not appear to be impossible, they are likely to be difficult to achieve in the 12-year period and might be increasingly costly.[46]

Strategies to achieve the Kyoto Protocol levels would probably not involve efficiency gains alone, but rather would also include fuel switching and product or service substitution. The former involves substitution of energy sources that do not have any net CO_2 emissions, such as renewables or nuclear-generated electricity, for fossil fuels. The latter involves using services or products that result in lower carbon emissions than those currently used; for example, using less energy intensive materials or modes of transportation. While such substitutions are possible, they would likely take several years to implement on a scale that would contribute significantly to carbon emission reduction.

Nevertheless, substitution, particularly zero-emission energy sources, appear to be an important consideration along with increased energy efficiency in any long-term strategy to reduce carbon emissions. While it is beyond the scope of this report to consider such substitutions in detail, an example is given here to show how that might work.[47] If one-half of the coal-fired capacity projected for the nation's electricity supply for 2008 could somehow be replaced by nuclear power and/or renewables, carbon emissions in 2008 would decline by about 15% from the current forecast. That change would lower by about two-thirds the energy reduction requirements that would be needed to meet the Kyoto Protocol levels. Furthermore, all end-uses, even those

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[46]For another view on this issue see Office of Energy Efficiency and Renewable Energy, Department of Energy, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*.

[47]The model built to perform the analysis presented above can also be used to calculate the effects of fuel substitution.

that used negligible amounts of electricity, would benefit if the burden of emission reduction were apportioned to all end-uses as is done in this report. The long lead time needed to build new power plants combined with material and personnel constraints, along with other environmental and regulatory issues, however, would likely preclude a substitution of that magnitude within 10 years. Over a longer period, such substitution is probably more feasible.

Carbon emission reduction to meet the Kyoto Protocol levels for the 2008-2012 period by reducing energy demand for current end-uses appears to be a substantial undertaking as seen in the above analysis. If apportioned to all end-uses, each would be affected significantly by 2008 given the reduction requirements and the currently forecast growth in that end-use. If all or a major portion of the energy demand reduction were a result of a lower level of service from that end-use rather than greater energy efficiency, consumers of those end-uses would likely be substantially affected.

Appendix: Detailed Data Tables

The following are the detailed data tables showing for each end-use the actual and forecast energy demand and carbon emissions for 1996, 2008, and 2012, the carbon emission levels and resultant energy demand levels needed to reach the Kyoto protocol levels of a 7% reduction from the 1990 levels, and the resultant changes from 1996, 2008, and 2012.

Energy Demand and Carbon Emissions — 1996
(Quads and Millions of Tons)

			Fuel										
End-use	**Sector**	**Symbol**	**Elect**	**Resid**	**Dist**	**NG**	**LPG**	**Coal**	**Bio**	**Gasol**	**Jet**	**Total**	**Carbon**
Light Duty Veh	TRANS	LDT			0.05					13.91		13.96	270.57
Direct Heat	IND	DHI	1.05	1.71	0.03	3.82	0.11	1.26				7.98	143.62
Space Ht	RES	SHR	1.74		0.88	3.76	0.31	0.05	0.61			7.35	106.45
Trucks	TRANS	FTT			3.47	0.01				1.12		4.60	91.08
Steam	IND	StI	0.09	0.32	0.04	3.38	0.08	1.03	1.83			6.77	85.78
Machine Drive	IND	MDI	4.93		0.02	0.10						5.05	80.90
Miscl	COM	MC	3.48		0.19	1.31						4.98	78.61
Air	TRANS	ArT								0.05	3.27	3.32	64.18
Appliances	RES	ApR	3.74			0.21	0.03					3.98	63.55
Lighting	COM	LC	3.71									3.71	59.49
Const & Ag	IND	CAI	1.74		0.90	0.26	0.10			0.15		3.15	54.23
Miscl	RES	MR	2.52			0.09	0.01					2.62	41.82
Water Heat	RES	WHR	1.16		0.09	1.32	0.07					2.64	40.71
Mining	IND	MnI	0.79	0.02	0.18	1.11	0.19	0.06		0.02		2.38	38.12
VAC	COM	ACC	2.20			0.02						2.22	35.64
Space Heat	COM	SHC	0.39		0.23	1.34	0.08	0.08				2.12	33.60
Marine	TRANS	MaT		0.44	0.96							1.40	28.61
A/C	RES	ACR	1.65									1.65	26.38
HVAC	IND	HAI	0.85			0.36						1.21	18.84
Lighting	RES	LR	1.10									1.10	17.59
Electrolysis	IND	ELI	1.02									1.02	16.36
Water Heat	COM	WHC	0.55		0.05	0.45						1.05	16.30
Rail	TRANS	RT	0.19	0.46								0.65	12.99
Lighting	IND	LI	0.75									0.75	12.03
Cook & Ref	COM	CRC	0.55			0.18						0.73	11.40
Pipeline	TRANS	PT				0.73						0.73	10.56
Elec Gen	IND	ELI				0.35						0.35	5.06
Totals			34.20	2.95	7.09	18.80	0.98	2.48	2.44	15.25	3.27	87.47	1464.46

Energy Use and Carbon Emissions — 2008
(Quads and Millions of Tons)

End-use	Sector	Symbol	Elect	Resid	Dist	NG	LPG	Coal	Bio	Gasol	Jet	Total	Carbon
			Fuel										
Light Duty Veh	TRANS	LDT			0.09	0.10				16.98		17.17	332.28
Direct Heat	IND	DHI	1.30	2.00	0.04	4.32	0.12	1.33				9.10	163.72
Frgt Trucks	TRANS	FTT			5.01					0.81		5.82	115.60
Miscl	COM	MC	4.94	0.12	0.18	1.57	0.09	0.09				6.98	114.12
Space Heat	RES	SHR	1.91		0.75	3.83	0.34	0.05	0.64			7.51	108.92
Air	TRANS	ArT								0.04	4.93	4.97	95.98
Machine Drive	IND	MDI	6.09		0.02	0.11						6.23	102.69
Steam	IND	StI	0.11	0.37	0.05	3.82	0.09	1.08	2.29			7.82	95.45
Miscl	RES	MR	4.50			0.10	0.01					4.61	75.93
Lighting	COM	LC	3.71									3.71	61.20
Appliances	RES	ApR	3.37			0.23	0.04					3.63	59.52
Const & Agric	IND	CAI	1.28		0.96	0.32	0.11					2.67	46.82
Mining	IND	MnI	0.98	0.02	0.22	1.26	0.11	0.06		0.03		2.67	43.10
Water Heat	RES	WHR	1.13		0.10	1.41	0.10					2.74	42.78
Marine	TRANS	MaT		0.77	0.92							1.68	34.74
Vent. and Air Cond	COM	ACC	2.18			0.02						2.20	36.33
Space Heat	COM	SHC	0.42		0.18	1.38						1.98	30.55
Air Conditioning	RES	ACR	1.63									1.63	26.88
HVAC	IND	HAI	1.05			0.41						1.46	23.23
Lighting	RES	LR	1.26									1.26	20.86
Electrolysis	IND	EI	1.15									1.15	19.06
Rail	TRANS	RT	0.42	0.44								0.86	16.35
Water Heat	COM	WHC	0.45		0.05	0.51						1.02	15.89
Pipeline	TRANS	PT				0.81						0.81	11.68
Cooking & Refrig	COM	CRC	0.57			0.22						0.79	12.56
Lighting	IND	LI	0.57									0.57	9.37
Elec Generation	IND	EGI				0.40						0.40	5.73
Totals			39.04	3.72	8.56	20.80	1.01	2.61	2.93	17.85	4.93	101.45	1721.33

Energy Demand and Carbon Emissions — 2012
(Quads and Millions of Tons)

			Fuel										
End-use	**Sector**	**Symbol**	**Elect**	**Resid**	**Dist**	**NG**	**LPG**	**Coal**	**Bio**	**Gasol**	**Jet**	**Total**	**Carbon**
Light Duty Veh	TRANS	LDT			0.09	0.12				18.20		18.42	356.35
Direct Heat	IND	DHI	1.33	1.98	0.04	4.41	0.13	1.33				9.21	165.24
Frgt Trucks	TRANS	FTT			5.20					0.84		6.04	120.01
Miscl	COM	MC	5.07	0.12	0.18	1.61	0.09	0.09				7.15	116.93
Space Heat	RES	SHR	1.99		0.73	3.92	0.34	0.05	0.65			7.68	111.22
Air	TRANS	ArT								0.04	5.45	5.49	106.21
Machine Drive	IND	MDI	6.26		0.03	0.12						6.40	105.47
Steam	IND	StI	0.11	0.37	0.05	3.90	0.09	1.08	2.38			7.99	96.68
Miscl	RES	MR	4.68			0.10	0.01					4.79	78.89
Lighting	COM	LC	3.80									3.80	62.78
Appliances	RES	ApR	3.50			0.23	0.04					3.77	61.79
Const & Agric	IND	CAI	1.32		1.01	0.32	0.11					2.76	48.43
Mining	IND	MnI	1.00	0.02	0.23	1.28	0.11	0.06		0.03		2.74	44.20
Water Heat	RES	WHR	1.17		0.10	1.45	0.10					2.82	44.03
Marine	TRANS	MaT		0.85	0.95							1.80	37.19
Vent and Air Cond	COM	ACC	2.24			0.02						2.26	37.26
Space Heat	COM	SHC	0.43		0.18	1.41						2.03	31.19
A/C	RES	ACR	1.69									1.69	27.94
HVAC	IND	HAI	1.08			0.42						1.49	23.83
Lighting	RES	LR	1.31									1.31	21.68
Electrolysis	IND	EI	1.19									1.19	19.58
Rail	TRANS	RT	0.51	0.48								0.99	18.80
Water Heat	COM	WHC	0.46		0.05	0.53						1.04	16.25
Pipeline	TRANS	PT				0.98						0.98	14.21
Cooking & Refrig	COM	CRC	0.59			0.22						0.81	12.88
Lighting	IND	LI	0.58									0.58	9.62
Elec Generation	IND	EGI				0.40						0.40	5.85
Totals			40.32	3.82	8.82	21.46	1.03	2.62	3.02	19.11	5.45	105.66	1794.51

End-Use Energy Demand and Carbon Emissions
(Quadrillions of Btus and Millions of Metric Tons)

	2008 Forecast		1996 Actual		2008 Kyoto Target		Energy Reductions		Carbon Reductions	
End-use	**Total**	**Carbon**	**Energy**	**Carbon**	**Energy**	**Carbon**	**From 2008**	**From 1996**	**From 2008**	**From 1996**
LDT	17.17	332.28	13.96	270.57	12.23	236.78	4.93	1.73	95.51	33.79
DHI	9.10	163.72	7.98	143.62	6.49	116.66	2.62	1.49	47.06	26.96
FTT	5.82	115.60	4.60	91.08	4.15	82.37	1.67	0.45	33.23	8.70
MC	6.98	114.12	4.98	78.61	4.97	81.32	2.01	0.01	32.80	-2.71
SHR	6.88	108.92	6.74	106.45	4.90	77.61	1.98	1.84	31.31	28.83
ArT	4.97	95.98	3.32	64.18	3.54	68.39	1.43	-0.22	27.59	-4.21
MDI	6.23	102.69	5.05	80.90	4.44	73.17	1.79	0.61	29.52	7.73
StI	5.53	95.45	4.94	85.78	3.94	68.02	1.59	1.00	27.44	17.77
MR	4.61	75.93	2.62	41.82	3.29	54.11	1.33	-0.67	21.82	-12.29
LC	3.71	61.20	3.71	59.49	2.64	43.61	1.07	1.07	17.59	15.88
ApR	3.63	59.52	3.98	63.55	2.59	42.41	1.04	1.39	17.11	21.14
CAI	2.67	46.82	3.15	54.23	1.90	33.36	0.77	1.25	13.46	20.86
MnI	2.67	43.10	2.38	38.12	1.90	30.71	0.77	0.48	12.39	7.41
WHR	2.74	42.78	2.64	40.71	1.95	30.48	0.79	0.69	12.30	10.22
MaT	1.68	34.74	1.40	28.61	1.20	24.76	0.48	0.20	9.99	3.85
ACC	2.20	36.33	2.22	35.64	1.57	25.88	0.63	0.65	10.44	9.75
SHC	1.98	30.55	2.12	33.60	1.41	21.77	0.57	0.70	8.78	11.83
ACR	1.63	26.88	1.65	26.38	1.16	19.16	0.47	0.48	7.73	7.23
HAI	1.46	23.23	1.21	18.84	1.04	16.55	0.42	0.17	6.68	2.29
LR	1.26	20.86	1.10	17.59	0.90	14.87	0.36	0.20	6.00	2.72
EI	1.15	19.06	1.02	16.36	0.82	13.58	0.33	0.20	5.48	2.78
RT	0.86	16.35	0.65	12.99	0.61	11.65	0.25	0.04	4.70	1.34
WHC	1.02	15.89	1.05	16.30	0.72	11.32	0.29	0.32	4.57	4.98
PT	0.81	11.68	0.73	10.56	0.58	8.33	0.23	0.15	3.36	2.24
CRC	0.79	12.56	0.73	11.40	0.56	8.95	0.23	0.17	3.61	2.45
LI	0.57	9.37	0.75	12.03	0.40	6.68	0.16	0.35	2.69	5.35
EGI	0.40	5.73	0.35	5.06	0.28	4.08	0.11	0.07	1.65	0.98
Totals	98.52	1721.33	85.03	1464.46	70.20	1226.59	28.32	14.83	494.75	237.88

End-Use Energy Demand and Carbon Emissions
(Quadrillions of Btus and Millions of Metric Tons)

	2012 Forecast		2008 Kyoto Target		Reductions	
End-use	**Energy**	**Carbon**	**Energy**	**Carbon**	**Energy**	**Carbon**
LDT	18.42	356.35	12.23	236.78	6.18	119.57
DHI	9.21	165.24	6.49	116.66	2.73	48.58
FTT	6.04	120.01	4.15	82.37	1.89	37.63
MC	7.15	116.93	4.97	81.32	2.18	35.60
SHR	7.03	111.22	4.90	77.61	2.13	33.61
ArT	5.49	106.21	3.54	68.39	1.96	37.82
MDI	6.40	105.47	4.44	73.17	1.96	32.29
StI	5.61	96.68	3.94	68.02	1.67	28.67
MR	4.79	78.89	3.29	54.11	1.51	24.79
LC	3.80	62.78	2.64	43.61	1.16	19.17
ApR	3.77	61.79	2.59	42.41	1.18	19.38
CAI	2.76	48.43	1.90	33.36	0.86	15.06
MnI	2.74	44.20	1.90	30.71	0.84	13.49
WHR	2.82	44.03	1.95	30.48	0.87	13.55
MaT	1.80	37.19	1.20	24.76	0.60	12.44
ACC	2.26	37.26	1.57	25.88	0.69	11.38
SHC	2.03	31.19	1.41	21.77	0.61	9.42
ACR	1.69	27.94	1.16	19.16	0.53	8.79
HAI	1.49	23.83	1.04	16.55	0.46	7.27
LR	1.31	21.68	0.90	14.87	0.41	6.82
EI	1.19	19.58	0.82	13.58	0.36	5.99
RT	0.99	18.80	0.61	11.65	0.38	7.15
WHC	1.04	16.25	0.72	11.32	0.32	4.93
PT	0.98	14.21	0.58	8.33	0.41	5.88
CRC	0.81	12.88	0.56	8.95	0.25	3.93
LI	0.58	9.62	0.40	6.68	0.18	2.95
EGI	0.40	5.85	0.28	4.08	0.12	1.77
Totals	102.64	1794.51	70.20	1226.59	32.43	567.93