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The Composition of a Quad of Buildings Sector Energy: Physical, Economic, and Environmental Quantities

T. J. Secrest
A. K. Nicholls

July 1990

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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Abstract

In an analysis conducted for the U.S. Department of Energy Office of Building Technologies (OBT), the Pacific Northwest Laboratory examined the fuel type composition of energy consumed in the U.S. buildings sector. Numerical estimates were developed for the physical quantities of fuel consumed, as well as of the fossil fuel emissions (carbon dioxide, sulfur dioxide, nitrogen oxides) and nuclear spent fuel byproducts associated with that consumption. Electric generating requirements and the economic values associated with energy consumption also were quantified. These variables were quantified for a generic quad (1 quadrillion Btu) of primary energy for the years 1987 and 2010, to illnstrate the impacts of a fuel-neutral reduction in buildings sector energy use, and for specific fuel types, to enable meaningful comparisons of benefits achievable through various OBT research projects or technology developments. Two examples are provided to illustrate how these conversion factors may be used to quantify the impacts of energy savings potentially achievable through OBT building energy conservation efforts.

Summary

The Office of Building Technologies (OBT) supports a number of research and development projects in the U.S. residential and commercial sectors in an effort to reduce overall buildings sector energy use, as well as the associated environmental emissions and expenditures associated with that energy consumption. A question frequently asked of OBT is, What are the quantifiable benefits of realized energy savings in the buildings sector? Or, put another way, Why is reduced energy use in buildings important to the country? The question often demands a quick answer for policy purposes and requires capturing the general magnitude of the potential benefits as opposed to providing very precise but time-consuming estimates.

In this context, the Pacific Northwest Laboratory examined the composition of energy consumed in the residential and commercial buildings sectors and developed a simple, straightforward fuel shares approach for quantifying the attributes of that energy consumption. The approach focuses on a "generic quad" of primary energy use, defined as a quad composed of primary fuels in amounts proportional to the shares of primary fuels supplied to the buildings sector.(a) When applied to estimate the benefits of reduced energy use, this "generic quad" is explicitly fuel-neutral and does not involve the use of energy supply curves.

This analysis provides detailed documentation supporting the derivation of the environmental and economic attributes associated with consumption of this generic quad. Attributes examined include physical fuel quantities, fossil fuel environmental emissions, electric generating capacity requirements, and the dollar expenditures associated with energy consumption. To provide two examples of how the generic quad approach can be used to estimate the benefits of buildings sector research and development efforts, this analysis quantifies the impacts that would be associated with potential energy savings achievable for the year 2010 with the overall OBT R&D effort and, more narrowly, with OBT's lighting research program.

Figures S.1 and S.2 show the composition of a generic quad of buildings sector energy in 1987 and 2010. The 1987 generic quad was developed from historical data from the U.S. Department of Energy (DOE) Energy Information Administration. The 2010 generic quad was developed from projections of future energy use by DOE's Office of Policy, Planning and Analysis. The 2010 generic quad therefore reflects the assumptions about future fuel use inherent in that report.

On the left-hand side of each figure, the composition of the generic quad is expressed in terms of trillion British thermal units (TBtu) of the primary source fuels and, where applicable, in terms of physical quantities. As is indicated by the flows of energy, the majority of the source fuels provide input for the generation of electricity. On the right-hand side of each figure is depicted the energy actually delivered to the building boundary, after accounting for the generation, transmission, and distribution losses associated with electricity production.

The composition of the primary source fuels changes significantly between 1987 and 2010, with major increases in coal and renewable energy, a slight increase in nuclear, and decreases in the other fuels. The on-site consumption of energy by five fuel types is dominated by electricity and

(a) To illustrate, if natural gas supplies 25% of total primary energy to buildings, from the combination of on-site gas use and gas-fired electricity, then the generic quad will contain 250 TBtu of natural gas.

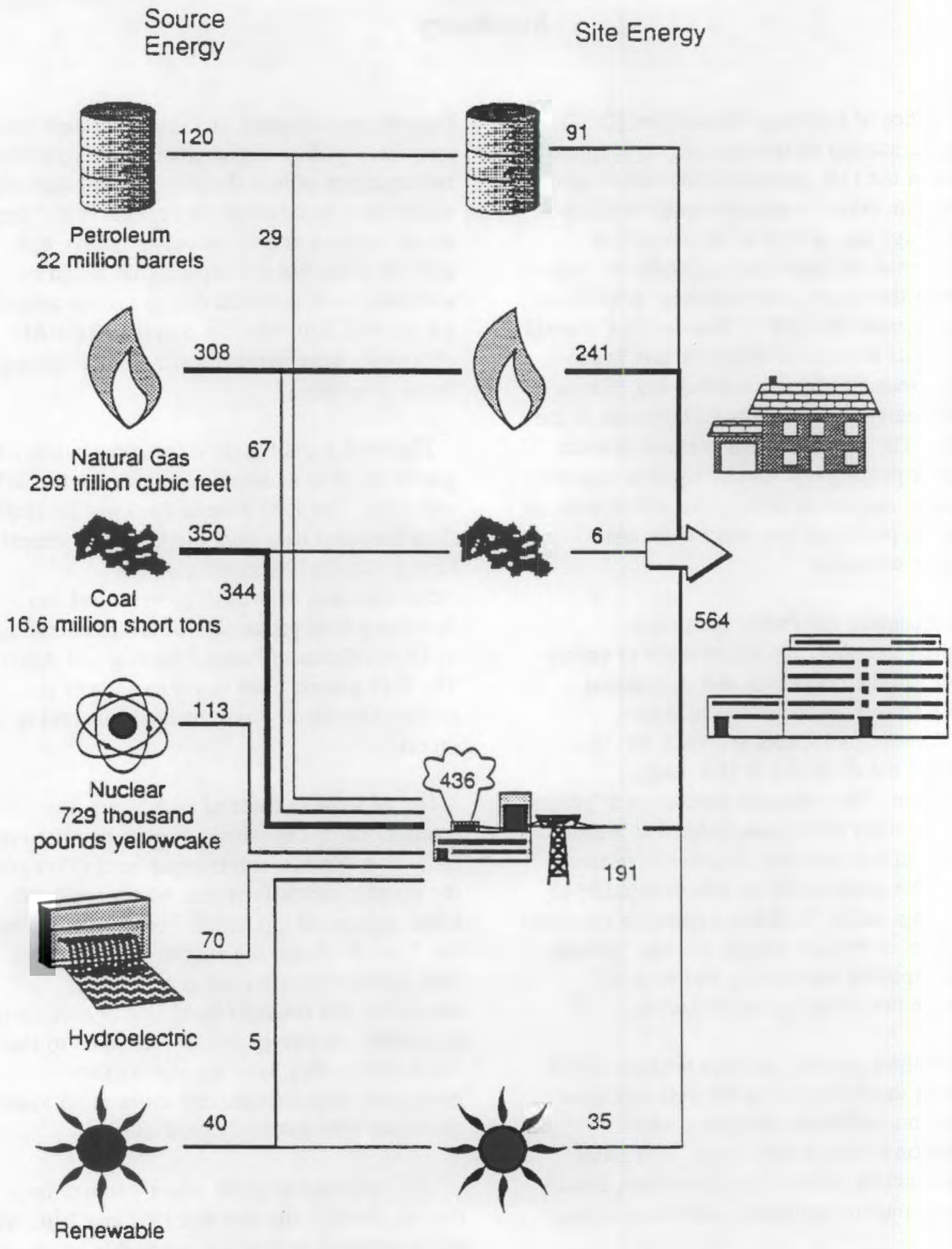

Figure S.1. One Generic Quad of Buildings Sector Primary Energy by Fuel Type and Physical Quantity, 1987

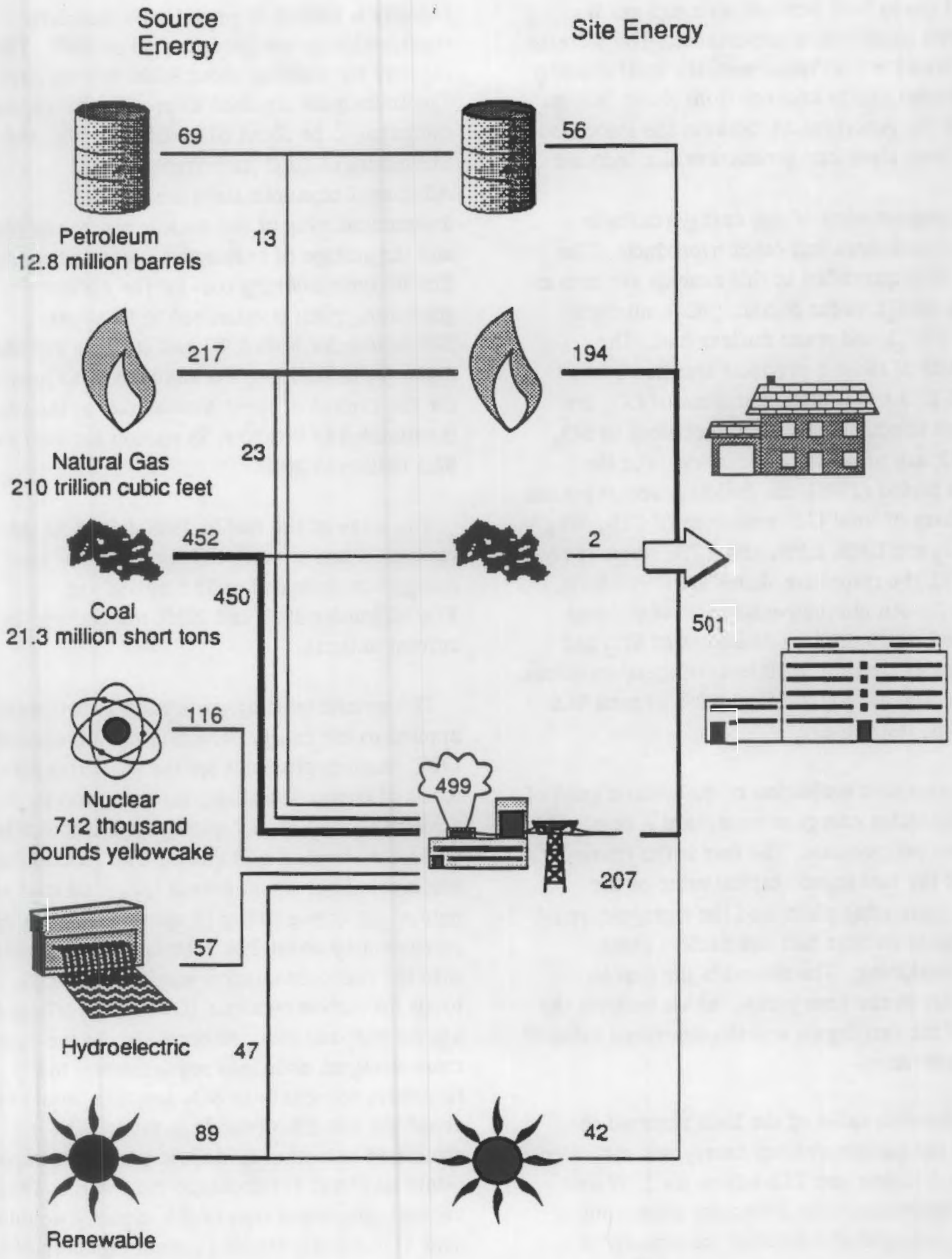

Figure S.2. One Generic Quad of Buildings Sector Primary Energy by Fuel Type and Physical Quantity, 2010 natural gas in both periods, although gas is projected to decline in importance. The increase in electricity is very important: the total quantity of delivered energy declines from about 56% to 50% of the generic quad, because the associated losses from electricity production also increase.

The consumption of this energy results in a range of emissions and other byproducts. The major ones quantified in this analysis are carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and spent nuclear fuel. The quantities of these byproducts are shown in Table S.1. As indicated, emissions of CO_2 are expected to remain level, and emissions of SO_2 and NO_x are projected to decrease. For the current period (1985), the buildings sector generic quad share of total U.S. emissions of CO_2, SO_2, and NO_x are 1.3%, 1.5%, and 0.7%, respectively. For 2010, the respective shares are 0.9%, 0.8%, and 0.4%. An alternative scenario considered increased restrictions on emissions of SO_2 and NO_x and showed the 2010 level of these emissions each to decrease to 0.6% and 0.2% of total U.S. emissions, respectively.

The economic evaluation of the generic quad of buildings sector energy consumption is developed from two perspectives. The first is the resource value of the fuel inputs, capital value of the electric generating plant, and the storage/disposal of the spent nuclear fuel and nuclear plant decommissioning. The second is the cost to consumers in the time period, which includes the value of the fuel inputs and the amortized value of capital resources.

The resource value of the fuels required to provide the generic quad of energy was estimated to be $1.3 billion and $3.2 billion for 1987 and 2010, respectively. The electricity generating capacity required and value of the capacity to provide the electricity component for the generic quad of energy by coal and nuclear-fueled generation are shown in Table S.2. As seen, a total of about 8,300 MW of electric generating capacity is needed to provide the electricity contribution to the generic quad in 1987. This capacity increases to about 9,900 MW in 2010. The investment required to provide this capacity is estimated to be about $11 billion in 1987 and $13 billion in 2010 (in current dollars). Additional economic costs are for the decommissioning of the nuclear generating plant and the storage of radioactive spent nuclear fuel. The decommissioning cost for the nuclear generating plant is estimated to be about $2.5 billion for both 1987 and 2010 (in current dollars). In addition, the annual cost to provide for the storage of spent nuclear fuel at the reactor is estimated to be about $3 million for 1987 and $2.3 million in 2010.

The value of the fuel in 1986 dollars to the residential and commercial consumers of the energy was estimated at $5.5 billion and $7.6 billion for 1987 and 2010, respectively (in current dollars).

The generic quad quantification factors were applied to the energy reduction potential for all OBT research programs for the year 2010 for two levels of energy reduction: an economically achievable level of 11.2 quads and a technically achievable level of 17.8 quads. The economically achievable level would reduce U.S. total coal and natural gas consumption by about 14% each, and petroleum by about 2%. The emissions associated with the fuel consumption would reduce U.S. totals for carbon by about 10%, and by 9% and 4% for SO_2 and NO_x, respectively. In the case of more stringent emissions requirements, the respective reductions in SO_2 and NO_x would be about 7% and 2% of the U.S. totals. The associated reduction in electric generating capacity would be about 111 thousand megawatts. The avoided investment cost of this capacity would be over $174 billion; avoided annual expenditures for fuel inputs would amount to $36 billion. Alternatively, the annual value of the energy savings to consumers would amount to about $85 billion.

Table S.1. Physical Quantities of Byproducts from 1 Quad of Buildings Sector Energy Consumption, 1987 and 2010

	CO_2, trillion grams carbon	SO_2, million lb SO_2	NO_x, million lb NO_2	Spent Nuclear Fuel, metric tons heavy metal
1987	15.7	654	310	36
2010	15.9	405	248	29

Table S.2. Electricity Generating Capacity and Capital Value of Generic Quad of Buildings Sector Energy Consumption, 1987 and 2010

	Coal		Nuclear		Total	
	Capacity, MW	Value, $ million	Capacity, MW	Value, $ million	Capacity, MW	Value, $ million
1987	6,387	6,387	1,896	4,914	8,283	11,301
2010	8,030	8,030	1,896	4,914	9,926	12,944

This analysis does not attempt to estimate the potential costs to society of achieving energy savings targets of the magnitude discussed here, because this is not a benefit-cost analysis. However, it is recognized that these costs are potentially large.

A comparable set of attributes was developed for the OBT lighting research program that has the potential to reduce electrical energy consumption by about 1.7 quads in 2010. In terms of primary fuels, total U.S. coal consumption would be reduced by about 3%, while oil and gas consumption would fall by nearly 1%. The associated carbon emissions would account for less than 2% of total U.S. carbon emissions. Emissions of SO_2 and NO_x would decline to about 2% and 1% of total emissions, respectively, with the shares decreasing to less than 1.5% and 0.5% in the event that more restrictive emissions requirements are in place. The reduction in electric generating capacity needs would amount to about 21.5 thousand megawatts, with a capital value of nearly $25 billion and fuel inputs valued at nearly $2.2 billion. The annual value of the energy savings to consumers would amount to nearly $12 billion.

The conversion factors developed provide a relatively quick means of developing the major attributes of alternative programs, to enable the comparison of their associated benefits.

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1.0 Introduction

Energy use in the buildings sector of the United States has contributed substantially to the steady rise in the nation's total energy consumption between 1960 and 1987. By 1987, the buildings sector alone accounted for 36% of the total energy consumed in the United States, up from 30% in 1960. Forecasters predict that this percentage will increase to 38% by the year 2010.

To reverse this trend, the U.S. Department of Energy (DOE) Office of Building Technologies (OBT) administers a program aimed toward improving the energy efficiency of buildings. The varied efforts in the OBT program involve research on, and development of, energy-efficient design strategies and building technologies. Ultimate implementation of these strategies and technologies will result in energy savings.

At the request of the OBT, the Pacific Northwest Laboratory (PNL) developed a methodology for quantifying the potential impacts associated with energy efficiency improvements of OBT conservation programs. The composition of the energy consumed by the buildings sector was analyzed and converted into numerical quantities, to develop fuel-neutral and fuel-specific conversion factors for use in quantifying the benefits of specific building energy conservation efforts. The methodology is focused to translate quantities of energy into the major attributes associated with the energy consumption; these attributes include the physical quantities of fuel inputs and byproducts and the economic value of the fuels.

This report documents the development of the methodology. In Section 2, historical and projected trends in both national and buildings sector energy use are reviewed. The primary fuels that supply the buildings sector are also detailed in this section. This background information supports the rationale for the analysis. The methodology and data sources used to develop the conversion factors are explained in Section 3. Section 4 provides complete descriptions of the conversion factors developed to obtain physical quantities of fuels and fuel consumption byproducts and to quantify the economic values associated with reduced fuel consumption. In Section 5, two examples are presented to demonstrate how the conversion factors can be applied to OBT efforts so that the benefits of alternative building energy conservation technologies can be easily compared. The methodology and key assumptions underlying the conversion factors are fully documented in Appendixes A through E, to enable replication or updating.

2.0 Background

The U.S. buildings sector consumes a substantial quantity of energy. The review of historical and forecast consumption trends presented in this section supports the rationale for this study. Energy consumption by the sector is also described further in terms of the shares, or percentages, of the total that are contributed by different fuel types. This information yields the basis for the approach taken in this study.

2.1 Energy Consumption Trends

Trends in national and sectoral energy use are documented and discussed in a number of sources (Carl and Scheer 1987; Holtberg et al. 1988; Office of Policy, Planning and Analysis 1988; Office of Conservation 1988; Brookhaven National Laboratory 1989; and Energy Information Administration 1989a, 1989g). This discussion is based on data from the Energy Information Administration (1989g) *State Energy Data Report: Consumption Estimates 1960 - 1987 (SEDR)* and on data and projections from the Office of Policy, Planning and Analysis (1988) *Long Range Energy Projections to 2010 (LREP)*. The discussion expresses the energy consumption in terms of primary energy. This is important, because the quantities and fuel shares provided for electricity are in terms of utility fuel inputs and, hence, include the generation and transmission losses to deliver the electricity to the building boundary. Other fuel types do not have the level of associated losses that electricity has.

As shown in Figure 2.1, total U.S. primary energy consumption rose from about 44 quads (1 quad = 10^{15} Btu) in 1960 to 77 quads in 1987, with an intermediate peak of 79 quads in 1979. Buildings sector primary energy use rose from about 13 quads to 28 quads in the same 27-year period, with an intermediate peak of 26 quads in 1978. The annual compound growth rate of buildings sector energy consumption over the 27-year period was 2.8%, compared to 2.1% for the United States as a whole. The result of this growth rate was an increase in thebuildings sector share of total U.S. energy consumption from 30% to 36% from 1960 to 1987.

The electrical energy share, including losses, of total U.S. consumption increased from about 19% of the total in 1960 to 36% in 1987. During the same 27-year period, the electrical energy share of total buildings sector consumption increased from 33% to 65%. The annual compound growth rate for electricity consumption during the period was 5.5% for the buildings sector, compared to 4.6% for the United States as a whole. The higher growth rate in buildings sector electricity consumption increased its share of total U.S. electricity consumption from about 52% in 1960 to 65% in 1987.

Looking ahead to the year 2010, the Office of Policy, Planning and Analysis (OPPA) projects total energy consumption levels to be about 108 and 41 quads for the United States and buildings sectors, respectively. The respective annual compound growth rates of 1.5% and 1.7% provide for a continued increase in the buildings sector share of the U.S. total energy consumption to 38%.

Electricity will increase to nearly 45% of the United States total and to 70% of buildings sector total energy consumption. The electricity consumption growth rate for the United States is projected to be about 2.6% for the upcoming 23-year period, with buildings sector electricity growth projected to be 2%. This increase in the U.S. electricity consumption growth rate relative to the buildings sector is projected to be due primarily to manufacturing sector energy requirements.

The historical and forecast information indicates that energy use in the buildings sector has significantly influenced the growth of energy consumption in the United States in recent history. The buildings sector share of the total

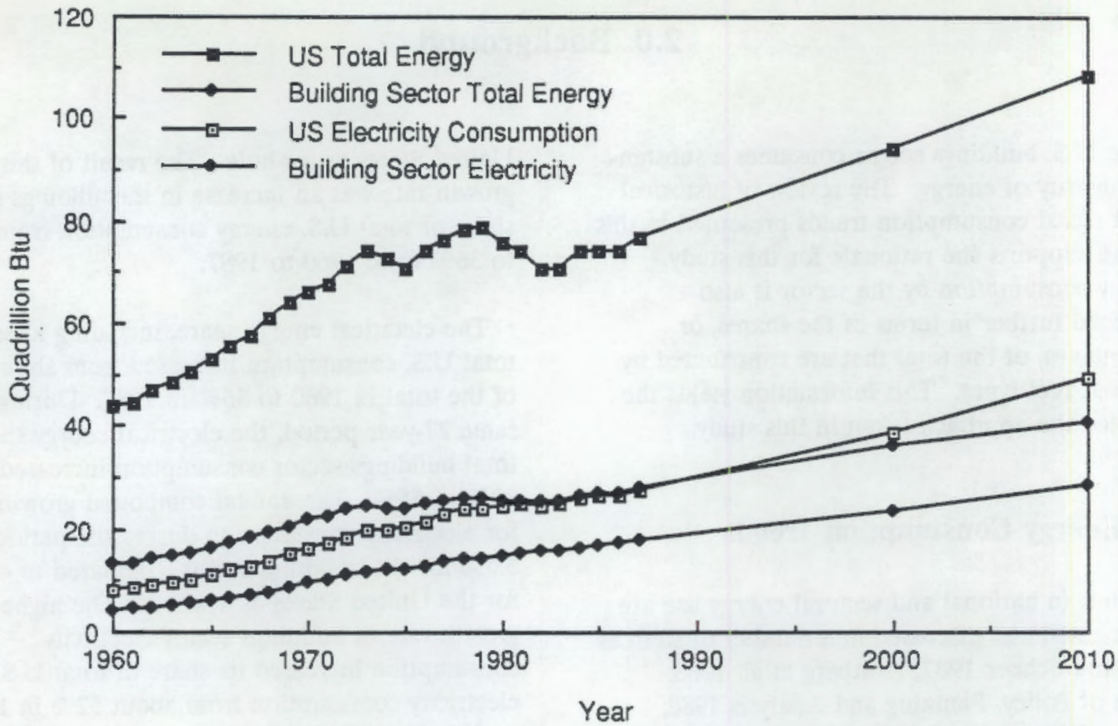

Figure 2.1. U.S. and Buildings Sector Primary Energy Consumption by Total and Electricity, 1960 Through 1987, 2000, and 2010

has risen to, and is expected to account for, over one-third of U.S. energy consumption in the year 2010.

Of particular significance is the share of building energy use in the form of electricity. The current electricity share is just under two-thirds and is projected to exceed two-thirds of buildings sector energy consumption in the year 2010. These proportions of U.S. energy requirements clearly identify the buildings sector as a key in reducing energy consumption levels, particularly when the reduction of 1 Btu of delivered electricity translates into a reduction of approximately 2.0 to 3.4 Btu to generate and deliver that energy, depending upon the generating technology. This analysis uses a figure of around 3.3 Btu, based on average coal-fired plant efficiencies.

2.2 Buildings Sector Fuel Shares

This section provides additional detail on the primary fuels that supply the buildings sector,combining the fossil and renewable fuels consumed on-site with the source fuels for electricity production.

Removing the electricity component provides an interesting look at building fuel use. For 1987, after the 63% of primary fuel input to generate and deliver electricity was removed, direct fuel consumed was in the form of 1% coal, 24% natural gas, 9% petroleum, and about 4% renewables. For the year 2010, after the 71% primary fuel input is subtracted, the direct fuel consumed remains at less than 1% for coal, 19% for natural gas, less than 6% for petroleum, and 4% for renewables.

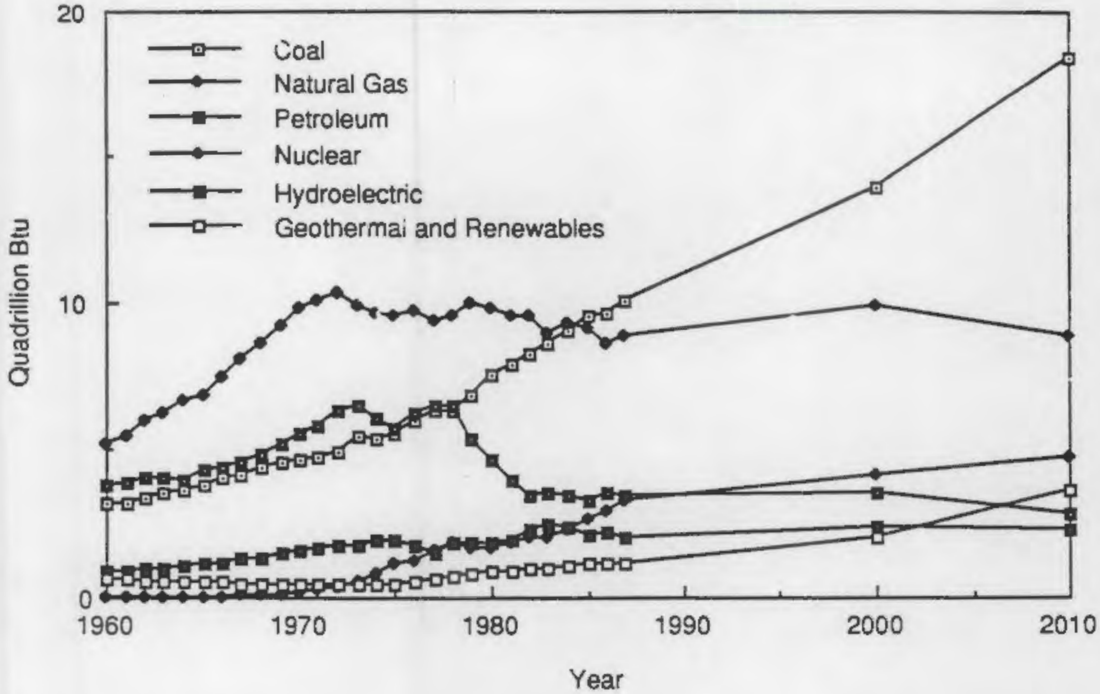

Figure 2.2. Buildings Sector Primary Energy Consumption by Fuel Type, 1960 Through 1987, 2000, and 2010

Figure 2.2 disaggregates the electricity component by primary fuel and adds it to on-site fossil and renewables use to show the fuel consumption for the period 1960 through 1987 and the projected levels for 2000 and 2010. This illustration provides the basis for the composition of the "generic quad" of buildings energy use. Coal and natural gas together have accounted for over 60% of total fuel use over the 1960 to 1987 period; the share of coal increased from 23% to 35% of the total, and natural gas decreased from 38% to 31%. Petroleum's share decreased from 28% in 1960 to 12% in 1987. Nuclear energy has increased from 0% to 11%, and geothermal and other renewables regained a share of about 4% after a decline in the 1970s. The share provided by hydroelectric has fluctuated between 6% and 8% of the total over the period.

In the year 2010, the *LREP* forecast shows coal to increase its share of total to 45%, natural gas to continue to decrease to 22%, petroleum to continue to decrease to 7%, nuclear energy to remain nearly constant at 12%, geothermal and renewables to increase to 9%, and hydroelectric to decrease slightly to 6% (Office of Policy, Planning and Analysis 1988).

Sharing out buildings sector energy use in this way clearly identifies the energy requirements for direct (on-site) and indirect (electricity source fuels) consumption paths. This carries implications about the benefits that may be realized from reducing consumption levels andabout strategies to pursue in affecting the consumption of target fuel types.

3.0 Approach

Two sets of conversion factors are developed in this section. The first translates a generic quad[(a)] of building primary energy use into its associated environmental byproducts and economic values at the national level. This provides a relatively simple method of identifying the benefits of building energy efficiency programs in a fuel-neutral sense. The second set provides the associated economic and noneconomic values per trillion British thermal units (TBtu) of specific fuel types, to enable the identification of the impact of focused program and technology initiatives. In this section, the methodology and data sources used to develop the conversion factors are described.

3.1 Conversion Factor Development Methodology

The generic quad conversion involves three steps. The first decomposes a generic quad of building energy into its constituent fuels, to provide expanded detail on the individual fuel share composition of total building energy use. The second step converts the source energy requirements to physical quantities of fuel and, for electricity, the capital requirements to generate the electric energy. The third step develops the conversion factors for the environmental emissions, nuclear spent fuel byproduct, and the economic values that are associated with the generic quad. This provides a means of assigning the values and benefits of conserving energy by simply multiplying by the number of quads targeted for reduction. The factors are developed for the 1987 and 2010 time periods so that relatively current and future building energy efficiency efforts can be evaluated. It should be noted that the generic quad conversion factor is sensitive to the composition of the quad and, to the extent that there are uncertainties in the energy supply-demand situation and economic assumptions used in the forecast, the 2010 conversion factor is itself a forecast of the economic and noneconomic values of avoided energy consumption.

The fuel-specific conversion factors are obtained in the process of developing the generic quad conversion factor. They are developed to translate the Btu quantities of fuel to the associated physical quantities, environmental byproducts, and economic values. These conversion factors make it possible to identify various attributes for a specific fuel type that may be a target of an efficiency effort. The fuel-specific conversion factors are also developed for the years 1987 and 2010. The physical conversions for the fuels are nearly constant for both time periods. In the case of electricity, the physical quantity of fuel inputs and fossil fuel emissions and waste byproducts for specific fuel generation types is subject to some uncertainty, depending upon the changes in generation efficiency and/or effluent removal efficiencies that may develop. The economic values for the year 2010 are, of course, subject to uncertainties in assumptions and methodologies used to develop forecasts of fuel prices and other economic factors.

Considerable attention is given to the losses that are incurred in the generation, transmission, and distribution of electricity, as electricity is a major fuel source for the buildings sector and

(a) A generic quad is defined as a quad composed of primary fuels in TBtu amounts proportional to the shares of fuels supplied to the buildings sector. To illustrate, if natural gas supplies 25% of total primary energy to buildings, from the combination of on-site gas use and gas-fired electricity, then the generic quad will contain 250 TBtu of natural gas. In this analysis, a generic quad is therefore fuel-neutral for the purpose of assessing the effects of energy conservation.

these combined losses are significant. Similar attention is not given to other fuel types; they do not comprise nearly as large a share of buildings sector energy requirements and the associated losses are considerably less significant. The only other fuel examined for losses to provide delivered energy is natural gas, which has reported transmission losses of less than 2%.

Emission quantities are developed for the carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and spent nuclear fuel, byproducts that result from energy conversion and are suspected of causing environmental damage or hazards. The environmental effects of energy extraction and renewable energy conversion and use (including hydropower) are not examined.

3.2 Data Sources

Various data sources are used to support the development of building energy consumption levels and the translations to the physical fuel quantities and associated emissions, electric generating capacity requirements, and economic valuations.

Two sources are used in developing the building energy consumption levels, the primary energy fuel inputs, and the conversions to physical quantities of fuel inputs. The *State Energy Data Report: Consumption Estimates 1960-1987 (SEDR)* provided the historical data for the analysis (Energy Information Administration 1989g). The *Long Range Energy Projections to 2010 (LREP)* provided projections of energy consumption for the years 2000 and 2010 (Office of Policy, Planning and Analysis 1988), and historical data on renewables.

The *SEDR* data are generated by the Energy Information Administration from data surveys it and other agencies conduct. Although the *SEDR* data may contain errors due to input data quality and assumptions, they are the most comprehensive and consistent data covering end-use sectors and the 1960 through 1987 historical period. The *SEDR*, published annually, contains a description of the input data sources and estimation methodologies. When this analysis was initiated, the *LREP* was the most currently available published DOE source that provides energy consumption forecasts out to the year 2010. It has been used as a baseline for DOE planning and analysis activities. In addition to the energy consumption data, the fuel price data and projections used to value the fuels were drawn from the January 1989 *Monthly Energy Review* (Energy Information Administration 1989e) and the *LREP*.

The development of spent nuclear fuel quantities for storage and disposal is based on *Commercial Nuclear Power 1989: Prospects for the United States and the World* (*Commercial Nuclear*) (Energy Information Administration 1989c) and *World Nuclear Fuel Cycle Requirements 1989* (*World Nuclear*) (Energy Information Administration 1989i). *World Nuclear* also contains projections of the quantities of uranium concentrate necessary for fabricating nuclear fuel. These projections are based on the forecasts of future commercial nuclear generation contained in *Commercial Nuclear*. The information from these two reports augments the data on nuclear Btu equivalents and energy shares from the *SEDR* and *LREP* to develop the physical quantities of uranium concentrate and spent fuel outputs for nuclear-fueled electricity generation.

The development of electricity capacity generating requirements is based upon data drawn from the *Historical Plant Cost and Annual Production Expenses for Selected Electric Plants 1986* and *1987* (*Historical Plant Costs*) (Energy Information Administration 1988, 1989d). These two reports provide the operating capacity factors for coal-fired electricity generating plants, for converting the direct electricity consumption to megawatts of capacity required to produce the electricity. Capacity factors for nuclear plants are drawn from *Annual Energy Review 1988* (Energy Information Administration 1989b). In addition, *Historical Plant Costs* provides information on the cost of capacity additions for both coal and nuclear plants.

Atmospheric emissions are developed from information contained in two reports. Carbon dioxide emissions are based upon information contained in *A Preliminary Analysis of U.S. CO_2 Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010* (Edmonds et al. 1989). Information on NO_x and SO_2 emissions is drawn from *Interim Assessment: The Causes and Effects of Acidic Deposition Volume II Emissions and Control* (National Acid Precipitation Assessment Program [undated]). Information on natural gas transmission and distribution losses is from *Natural Gas Annual 1988: Volume I* (Energy Information Administration 1989f).

4.0 Conversion Factor Development

The conversion factors developed to translate the buildings sector generic quad of primary energy into the physical quantities of fuel inputs, electrical capacity generating requirements, economic valuations, and environmental byproducts resulting from energy conversion are described in this section. Section 4.1 documents the conversion of the fuels from British thermal units (Btu) consumed to the physical quantities of fuel inputs. Section 4.2 describes the conversion of fossil fuels to emissions of carbon dioxide, sulfur dioxide, and oxides of nitrogen. In Section 4.3, conversions are provided for the development of electrical generating capacity requirements, nuclear plant decommissioning, treatment of spent nuclear fuel, annual fuel requirements, and the value of the fuels to consumers.

4.1 Fuel Conversion

A generic quad of primary energy consumed by commercial and residential buildings is converted to the physical quantities of fuels required to provide the energy. This is accomplisbed through three steps. The first, described in Section 4.1.1, examines the Btu quantities of fuels and shares consumed directly in the buildings sector for the period 1960 to 1987 and the year 2010. Section 4.1.2 provides the corresponding source fuel inputs and shares. The conversion of the Btu fuel inputs to physical fuel quantities is provided in Section 4.1.3.

4.1.1 Site Fuel Consumption and Shares

The direct, primary energy consumption and fuel shares in the buildings sector are examined for the historical period 1960 to 1987 and for projected use to 2010. Direct energy consumption refers to energy consumed at the building site by energy form. The direct electricity consumption is expressed as the primary energy that is required to generate and transmit the delivered energy. The *SEDR* data reveal that, on average, approximately 3.4 Btu of primary energy input are required to deliver 1 Btu of energy at the building site because of generating plant conversion efficiencies and transmission losses (Energy Information Administration 1989g).

Table 4.1 shows historical estimates and projections of direct energy consumption in the buildings sector by fuel type for the period 1960 through 2010. The buildings sector energy consumption has increased from 13.6 quads in 1960 to 28.7 quads in 1987. According to long-range projections made by the Office of Policy, Planning and Analysis, this figure is expected to increase to 40.7 quads in 2010. Electricity, as expressed in source energy, has been the dominant fuel for the historical period. Its share of building energy use is projected to increase from about 63% in 1987 to 71% in 2010. Coal and petroleum have declined in relative importance over the historical period, and natural gas' share has declined since 1970. Petroleum and natural gas are expected to continue to decline as a share of the total through 2010. Coal consumption is expected to remain relatively stable at less than 1%. Renewable energy supplies have shown a decline for the historical period and are forecast to increase somewhat by 2010. The renewable resource includes solar, wind, wood, and other renewable fuels that are consumed at the building site.

4.1.2 Source Fuel Shares

Although the site energy requirements data are informative, it is important to examine the quantity and distribution of fuels after splitting the electricity component into the source fuels required for generation. This is accomplished by applying the shares of input fuels to electric utilities to the quantities of electricity shown in Table 4.1. In this calculation, it is assumed that

Table 4.1. Direct Primary Energy Consumption and Fuel Shares in the Buildings Sector, 1960 Through 1987, 2000, and 2010

Year	Coal	Natural Gas	Petroleum	Electricity	Renewables	Total
	Consumption, TBtu					
1960	980.4	4267.7	3492.8	4,292.5	600.0	13,633.4
1965	610.5	5502.6	3867.1	6,039.0	500.0	16,519.2
1970	370.5	7407.2	4306.3	9,570.2	400.0	22,054.2
1975	208.1	7580.3	3804.6	12,303.5	400.0	24,296.5
1980	147.7	7521.1	3035.4	14,951.2	800.0	26,455.4
1985	176.5	7069.4	2572.5	17,016.2	1000.0	27,834.6
1987	165.0	6919.3	2618.4	18,027.8	1000.0	28,730.5
2000	200.0	8300.0	2700.0	23,405.6	1300.0	35,905.6
2010	100.0	7900.0	2300.0	28,736.4	1700.0	40,736.4
	Shares, Percent(a)					
Year	Coal	Natural Gas	Petroleum	Electricity	Renewables	Total
1960	7.2	31.3	25.6	31.5	4.4	100
1965	3.7	33.3	23.4	36.6	3.0	100
1970	1.7	33.6	19.5	43.4	1.8	100
1975	0.9	31.2	15.7	50.6	1.6	100
1980	0.6	28.4	11.5	56.5	3.0	100
1985	0.6	25.4	9.2	61.1	3.6	100
1987	0.6	24.1	9.1	62.7	3.5	100
2000	0.6	23.1	7.5	65.2	3.6	100
2010	0.2	19.4	5.6	70.5	4.2	100

(a) Shares may not sum to 100% due to rounding.

the electric utility input fuel shares apply equally to all consuming sectors.

The shares of input fuels to electric utilities for the historical and forecast period are shown in Table 4.2. Coal has been the major source fuel for generating electricity. From less than 45% of total fuel input in the mid-1970s, its share is projected to increase to nearly 64% of the total in 2010. Natural gas and petroleum increased as a share of utility fuel input during the historical period to offset the decline in coal use. However, their combined share has decreased since the mid-1970s. They are projected to continue to decline as a share of utility fuel inputs. As a share of total fuel input, hydroelectric-supplied electricity has declined and is projected to continue to decline. Nuclear has shown a steady increase to the present, but is expected to decline slightly by 2010. Utility fuel inputs in the form of renewable resources have not been a major fuel source, but are projected to supply nearly 7% of

Table 4.2. Electric Utility Energy Input Shares by Fuel Type, 1960 Through 1987, 2000, and 2010

Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
	Shares, Percent[a]						
1960	51.6	21.8	6.7	19.8	0.1	0.0	100
1965	52.8	21.8	6.5	18.4	0.4	0.0	100
1970	44.4	24.9	13.0	16.1	1.5	0.1	100
1975	43.2	15.9	15.6	15.7	9.3	0.3	100
1980	49.6	15.5	10.7	12.6	11.2	0.4	100
1985	55.0	11.9	4.1	12.6	15.6	0.8	100
1987	54.9	10.6	4.6	11.1	18.0	0.9	100
2000	58.8	7.0	3.6	10.0	17.4	3.1	100
2010	63.7	3.2	1.8	8.1	16.4	6.6	100

(a) Shares may not sum to 100% due to rounding.

Table 4.3. Buildings Sector Primary Fuel Shares by Source Fuel Type, 1960 Through 1987, 2000, and 2010

Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
	Shares, Percent[a]						
1960	23.4	38.2	27.7	6.2	0.0	4.4	100
1965	23.0	41.3	25.8	6.7	0.1	3.0	100
1970	21.0	44.4	25.2	7.0	0.6	1.8	100
1975	22.7	39.2	23.5	7.9	4.7	1.8	100
1980	28.6	37.2	17.5	7.1	6.3	3.3	100
1985	34.3	32.7	11.8	7.7	9.6	4.1	100
1987	35.0	30.8	12.0	7.0	11.3	4.0	100
2000	38.9	27.7	9.9	6.5	11.4	6.5	100
2010	45.2	21.7	6.9	5.7	11.6	8.9	100

(a) Shares may not sum to 100% due to rounding.

utility sector energy by 2010. The primary renewables for electric utilities are geothermal and wind.

The final step in developing the primary energy requirements for the buildings sector is to multiply the utility input fuel shares by the electricity share in Table 4.1 and then to distribute these input fuel shares by the appropriate primary fuel type. The results of these steps, the primary fuel shares for buildings sector consumption, are shown in Table 4.3. This table indicates that the share of coal-supplied energy has increased from about 23% in 1960 to 35% in 1987 and is projected to continue to increase to 45% in 2010. Natural gas and petroleum combined have decreased from nearly two-thirds of building primary energy to 42% in 1987, with their combined share projected to decrease to under 30% by 2010. The share supplied by nuclear has increased from 0 to 11% and is projected to provide 12% by 2010. The hydroelectric share has fluctuated between 6% and 8% over the historical period and is expected to decrease slightly to 6% by 2010. Energy provided by the total of other renewables and geothermal has fluctuated between 1% and 5% over the historical period and is projected to increase to nearly 9% by 2010.

To develop the generic quad of energy that meets buildings sector energy requirements, the shares for 1987 and 2010 (from Table 4.3) are simply expressed in TBtu; these are shown in Table 4.4. Additional detail on the decomposition of the generic quad is contained in Appendix A.

4.1.3 Conversion to Physical Quantities

The primary fuel inputs displayed in Table 4.4 in terms of TBtu are converted to the associated physical quantities of fuel (e.g., tons of coal, barrels of oil). Because no comparable physical equivalents exist for hydropower and renewables, no attempt was made to convert these fuel inputs. The conversions for the three fossil fuels are based upon conversion factors derived from the *SEDR* data. The conversion for nuclear is drawn from *Commercial Nuclear* and *World Nuclear*. These conversions are discussed in detail in Appendix B.

In the case of the fossil fuels, apparent differences exist with the fuel quality provided to the commercial, residential, and electric utility sectors. The differences in fuel quality and the fuel mix, i.e., whether directly consumed or consumed in the form of electricity, are treated separately to develop a weighted quantity per TBtu of primary fuel input. These weighted physical quantities of fuel input are shown in Table 4.5. These data show that, for every TBtu of primary energy consumed in the buildings sector in 1987, the physical quantity of fuel required is approximately 47 thousand tons of coal, or 971 billion cubic feet of natural gas, or 183 thousand barrels of petroleum, or about 6.5 thousand pounds of uranium concentrate or "yellowcake," the input fuel for nuclear plants.

Table 4.4. Generic Quad of Buildings Sector Source Fuels, 1987 and 2010

	TBtu					
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables
1987	350	308	120	70	113	40
2010	452	217	69	57	116	89

Table 4.5. Physical Quantities of Fuel per TBtu of Buildings Sector Primary Energy, 1987 and 2010

Year	Coal, thousand short tons	Natural Gas, billion ft^3	Petroleum, thousand bbl	Yellowcake, thousand lb
1987	47.4	971	183	6.46
2010	47.2	966	185	6.14

The final step in developing the physical fuel quantities is to multiply the physical quantities per TBtu from Table 4.5 by the primary fuel requirements shown in Table 4.4. The product of this calculation, shown in Table 4.6, is the physical quantities of fuel inputs that are required to provide the generic quad of energy to the buildings sector.

For 1987, the generic quad required about 17 million short tons of coal, 299 trillion cubic feet of natural gas, 22 million barrels of petroleum, and 729 thousand pounds of yellowcake. Based upon the *LREP* forecasts of energy consumption and input fuel mix to electric utilities, coal is projected to increase, with decreases in natural gas, petroleum, and yellowcake inputs to provide the generic quad (Office of Policy, Planning and Analysis 1988).

4.1.4 Summary

In this section, the above discussion is consolidated to present the generic quad of buildings sector energy requirements from physical quantity source energy inputs to delivered energy. Figures 4.1 and 4.2 illustrate the energy flows for 1987 and 2010, showing the direct consumption of fuels in buildings and the indirect consumption through the generation and transmission of electricity. The associated physical quantities of fuel required to provide the energy are also shown on the left-hand side of each figure.

For the 1987 generic quad of energy, Figure 4.1 shows that approximately 56% of the energy is delivered to the building boundary. The remainder is lost in the generation, transmission, and distribution of electricity. Natural gas and electricity are the two major fuels consumed at the building boundary. Coal and natural gas are the two major primary energy fuels; virtually all of the coal consumption occurs in the electric utility sector.

The composition of the 2010 generic quad of energy illustrated in Figure 4.2 shows the quantity of delivered energy decreasing to approximately 50% of the primary energy, because the share of electric energy increases and associated transmission and distribution losses are greater. Natural gas and electricity are projected to continue to provide most of the delivered energy to the buildings sector. Of the generic quad of primary energy, 71% is consumed indirectly by providing fuel for electricity generation.

4.2 Byproduct Conversions

Byproducts associated with the generic quad of energy result from the conversion of fuel to delivered energy. The byproducts identified are 1) emissions of CO_2, SO_2, and NO_x that result from burning fossil fuels and 2) the radioactive spent nuclear fuel that must be stored at a reactor or in a long-term repository. The three emissions byproducts are important because CO_2 has been identified as the most important anthropogenic contributor to global warming and SO_2 and NO_x have been identified as the primary precursors of acidic deposition, one manifestation of which is "acid rain." Solid waste products such as ash are not examined because data are not readily available and these products are not currently perceived as a major environmental issue.

Table 4.6. Physical Quantities of Fuel Required to Provide 1 Generic Quad of Energy to the Buildings Sector, 1987 and 2010

Year	Coal, million short tons	Natural Gas, trillion ft^3	Petroleum, million bbl	Yellowcake, thousand lb
1987	16.6	299	22.0	729
2010	21.3	210	12.8	712

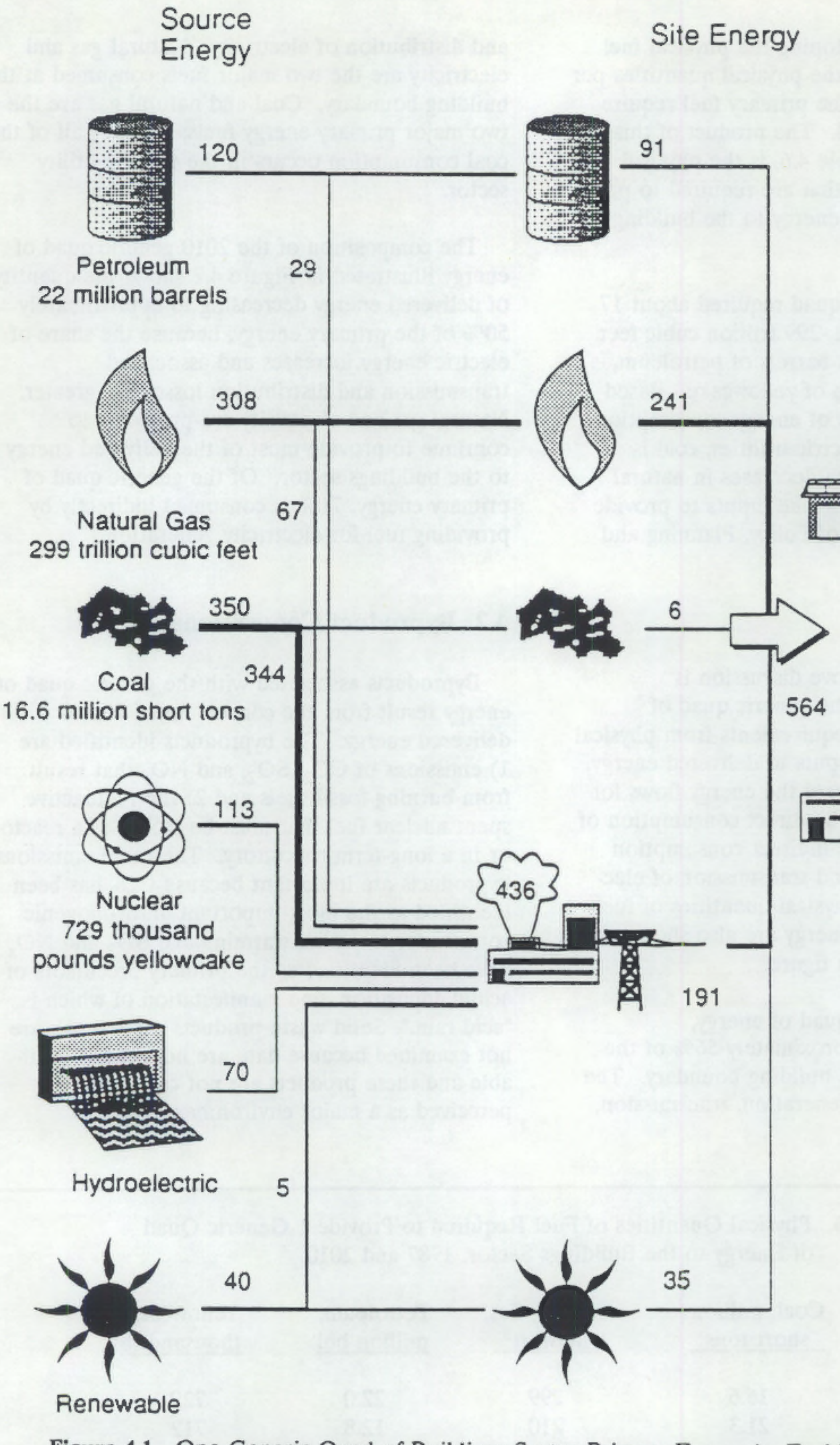

Figure 4.1. One Generic Quad of Buildings Sector Primary Energy by Fuel Type and Physical Quantity, 1987

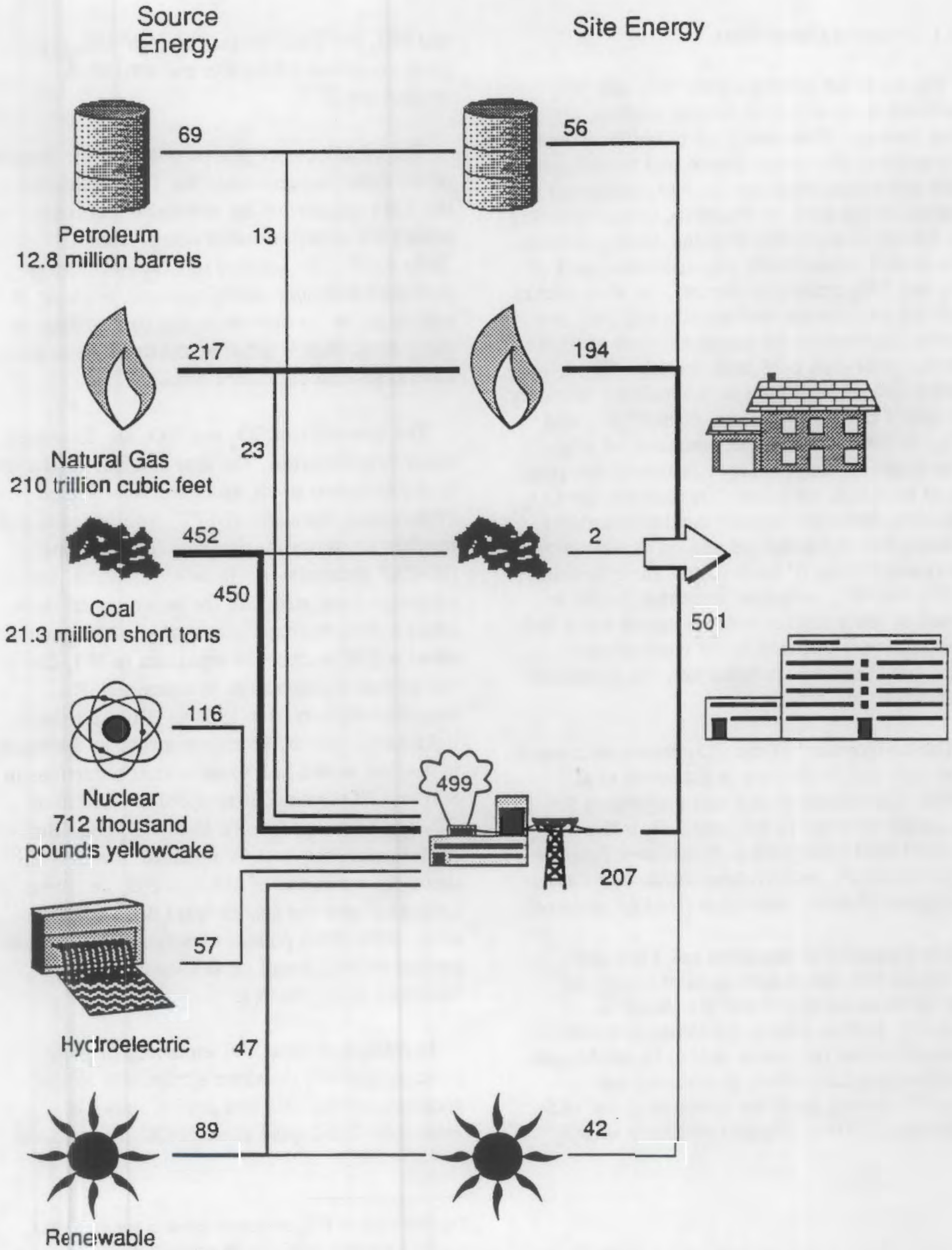

Figure 4.2. One Generic Quad of Buildings Sector Primary Energy by Fuel Type and Physical Quantity, 2010

4.2.1 Emission Conversions

The focus for developing the SO_2 and NO_x emissions is on coal-fired electric utilities, for three reasons. First, nearly all of buildings' coal consumption (the major source fuel for SO_2 emissions and a significant one for NO_x emissions) is indirect, in the form of electricity, so that omitting the emissions associated with the direct consumption of coal causes hardly any understatement of SO_2 and NO_x emissions. Second, the data sources used did not provide detailed SO_2 and NO_x conversion information for petroleum-fired utilities and for fossil fuels consumed directly. Third, combustion of fossil fuels at the building boundary is a minor contributor to emissions of SO_2 and NO_x. In 1980, for example, emissions of SO_2 from direct buildings energy constituted less than 5% of total U.S. emissions. By contrast, the CO_2 quantities developed include the direct building consumption of natural gas and oil as well as the utility combustion of fossil fuels. The quantities of SO_2 and NO_x emissions presented should be viewed as low estimates because not all fossil fuel consumption is included in the conversions. Appendix C explains in detail how the quantities of emissions are developed.

The development of the CO_2 emissions is based upon data and projections in Edmonds et al. (1989). The source of data and projections for the emissions levels of SO_2 and NO_x is the National Acid Precipitation Assessment Program report (*NAPAP*), *Interim Assessment: The Causes and Effects of Acidic Deposition* (NAPAP undated).

The quantities of emissions per TBtu and associated with the generic quad of energy for each of the three byproducts are shown in Table 4.7. Carbon dioxide emissions, expressed in grams of carbon (gc), show coal to be the highest contributor at 25.1 billion gc emission per TBtu.[a] Natural gas is the lowest at about 14.5 billion gc per TBtu. Current emissions of SO_2 and NO_x per TBtu for the "average" coal-fired plant are about 1.9 million and 890,000 lb, respectively.[b]

The emissions per generic quad are the product of the emissions quantities per TBtu multiplied by the TBtu quantity of the respective fuel comprising the generic quad of energy from Table 4.4.[c] The quantity of CO_2 emissions is projected to remain nearly constant, at about 16 trillion gc, as the increase in the coal content of the generic quad is offset by the decrease in the natural gas and petroleum content.

The quantities of SO_2 and NO_x are developed under two scenarios. The first assumes no change in the emissions levels under the New Source Performance Standards (NSPS) requirements, that regulate emissions for new capacity additions (NAPAP undated). As Table 4.7 indicates, the emissions associated with the generic quad show about a 38% decrease in emissions of SO_2 and about a 20% decrease in emissions in NO_x due to the increased penetration of cleaner, NSPS-regulated capacity from 1987 to 2010. Further tightening of the NSPS requirements, as discussed in NAPAP, would lead to significant reductions in SO_2 and NO_x emissions to about 675,000 lb of SO_2 per TBtu and 300,000 lb of NO_x per TBtu. In this event, the "high-compliance" scenario shows the quantities of SO_2 and NO_x emissions associated with the generic quad decreasing to about 304 million pounds of SO_2 and 135 million pounds of NO_2; detail on this scenario is contained in Appendix C.

In relation to total U.S. emissions of these three byproducts, the share attributable to the generic quad for 1985 and 2010 is shown in Table 4.8. The 1-quad share of CO_2 is projected

(a) In the global warming literature, CO_2 emissions are usually expressed in terms of grams of carbon.

(b) Emissions of NO_x are usually stated in pounds of NO_2. NO_x converts to NO_2 in the atmosphere.

(c) For SO_2 and NO_x the emissions are developed only for the 450 TBtu of coal consumed by utilities and do not include the negligible direct coal consumption.

Table 4.7. Emissions of CO_2, SO_2, and NO_x per TBtu and per Generic Quad of Buildings Sector Energy Consumption, 1987 and 2010

	Emissions per TBtu			Emissions per Generic Quad		
	CO_2, billion gc	SO_2, thousand lb[a]	NO_x, thousand lb[a]	CO_2, trillion gc	SO_2, million lb[a]	NO_x, million lb[a]
1987						
Coal	25.1	1900	890	8.79	654	310
Natural Gas	14.5			4.45		
Petroleum	20.3			2.43	—	—
Total				15.67	722	292
2010						
Coal	25.1	900	550	11.35	405	248
Natural Gas	14.5			3.15		
Petroleum	20.3			1.40	—	—
Total				15.89	405	248

(a) See text for 2010 high-compliance levels.

Table 4.8. Generic Quad of Buildings Sector Emissions Share of U.S. Totals for CO_2, SO_2, and NO_x, 1985 and 2010

	% of U.S. Total		
	CO_2	SO_2	NO_x
1985	1.3	1.5	0.7
2010	0.9	0.8	0.4

to decrease roughly in proportion to the building sector 1-quad share of total U.S. energy consumption. The shares of SO_2 and NO_x are projected to decline over the period for the case considering no change in the current NSPS emissions requirements. This is because total U.S. SO_2 and NO_x emissions are projected to increase and because new NSPS-regulated capacity will come on line and replace pre-NSPS capacity. These increases more than offset the increasing share of coal in the generic quad. For the NSPS high-compliance case, the emissions of both SO_2 and NO_x are projected to account for about 0.6% and 0.2% of their respective U.S. totals in 2010.

4.2.2 Spent Nuclear Fuel Conversion

The conversion to spent nuclear fuel is treated in detail in Appendix B. Spent nuclear fuel is typically stored for a period at the reactor in a water pond and in the future may be sent to a geologic repository for long-term storage.[a] Although spent fuel differs from the emissions byproducts, it is a byproduct of the energy conversion process and requires special treatment and handling.

The quantities of spent fuel per TBtu for 1987 and 2010 are 0.32 and 0.25 metric tons of heavy

(a) This facility has not yet been identified.

metal (MTHM), respectively. The quantity of spent fuel associated with the generic quad is the product of the MTHM per TBtu multiplied by the contribution of nuclear to the generic quad, shown in Table 4.4. Thus, 36 and 29 MTHM are associated with the generic quad of energy for 1987 and 2010, respectively.

4.3 Economic Valuations

The development of the economic values of the generic quad of energy is summarized in this section; Appendix D provides additional detail. The economic values are summarized from two general perspectives. The first is the cost of supplying electrical energy, which includes electrical generating capacity, fuel input costs to utilities, and the storage and disposal of spent nuclear fuel. The second is the value of the energy to the building owners and occupants who are the consumers of the delivered energy.

The electric energy component is examined from these two perspectives, because the first shows the major investment and operating costs associated with the supply of electrical energy and the second provides the annual operating and maintenance costs to supply the energy plus a fraction of the capital assets. The valuations for the electric energy supply component should **not** be added to those for the consumer perspective.

4.3.1 Electric Energy Supply Valuation

Major costs developed for the provision of electric energy associated with the generic quad of energy are for electric generating capacity, fuel inputs, and nuclear fuel storage and disposal. These costs are summarized in the following subsections.

Electric Generating Capacity Valuation

The development of the value of the electric energy generating capacity to supply the electricity component of the generic quad involves three steps. The first is to assign the shares of electric generating capacity additions by capacity type. The second is to translate the delivered electric energy associated with the generic quad to generating capacity needs by capacity type. The third is to develop the value of the capacity additions.

Because the objective of this analysis is to quantify major attributes/components of the generic quad, only the additions of coal and nuclear capacity are treated, as they comprise 73% and 80% of fuel input for electricity generation for 1987 and 2010, respectively. In addition, to 2010 the major utility capacity additions projected by *LREP* are coal and nuclear; renewables also increase, but these capital costs are difficult to quantify. For the same reason, no attempt is made to distinguish peak from baseload generating capacity, as coal and nuclear generating plants tend to be baseload capacity.

The amount of delivered electricity associated with the generic quad that is provided by coal- and nuclear-fueled generation is first developed in terms of TBtu and then translated to kilowatts of capacity by fuel type. The shares from Table 4.2 for coal- and nuclear-fueled capacity (63.7% and 16.4%, respectively) are then applied to the total delivered electricity shown in Figures 4.1 and 4.2 to provide the quantities of delivered electricity associated with these two capacity types for 1987 and 2010. In 1987, coal and nuclear provided 105 and 34 TBtu of delivered electricity, respectively, and 132 and 34 TBtu of delivered electricity in 2010.

The second step is to translate the delivered units of electricity to generating capacity. This is accomplished using the following formula:

$$kW = (TBtu\ electricity) / (3412\ Btu/kWh) / (8760\ hr/yr) / Capacity\ Factor$$

Capacity factor values for coal (0.55) and nuclear (0.6) generation are representative for recent industry averages documented in *Historical Plant Costs 1986* and *1987* and the *Annual Energy Review 1988* (Energy Information Administration 1988, 1989b,d). The capacity additions assigned to the coal-fueled generation of 105 TBtu for 1987 and 132 TBtu for 2010 applied to the formula with a 0.55 capacity factor are about 6.387 million kW and 8.030 million kW, respectively. The comparable additions for nuclear capacity are 1.896 million kW for both years because the quantity of delivered electricity is approximately the same. These capacity quantities associated with the generic quad of energy additions represent a requirement of about thirteen 500-MW coal-fueled and two 1000-MW nuclear-fueled power plants in 1987, and sixteen 500-MW coal-fueled and two 1000-MW nuclear-fueled plants in 2010.

The value of these additions is developed from the actual cost of recently constructed power plants. This experience has shown coal-fueled capacity to cost about $1000/kW and nuclear to be about $2600/kW. At these per unit costs, the installed capital value of these facilities amounts to approximately $11.3 billion in 1987 and $13.0 billion in 2010.

An additional cost factor for nuclear generating facilities is the cost associated with decommissioning, estimates of which vary widely in the decommissioning literature (from 5% to 200% of the original investment cost). This report uses a decommissioning estimate equal to 50% of the original investment cost, a mid-range value. This amounts to $2.5 billion for the nuclear capacity additions associated with the generic quad. Adding decommissioning costs to the investment costs provides a total capital value of $15.5 billion for the coal and nuclear generating capacity necessary to provide their share of the generic quad in 2010. (See Appendix D for more detail.)

Fuels Valuation

The value of the fuel inputs for 1987 and 2010 are developed for coal, natural gas, petroleum, and yellowcake using the resource values for these fuels. The prices for the three fossil fuels are taken from *LREP*. The price for uranium is based on the current domestic price from the *Uranium Industry Annual* (Energy Information Administration 1989h). The physical quantities of the four fuels are multiplied by their respective prices for the two time periods to obtain their values for the generic quad as shown in Table 4.9. The combined value of these fuels increases from $1.3 billion in 1987 to $3.2 billion in 2010.

Nuclear Fuel Storage and Disposal Valuation

An additional fuel-related consideration is the storage of irradiated spent fuel discharged from nuclear power plants. Following the assumptions and cost estimates of the *Final Version Dry Cask Storage Study* (Office of Civilian Radioactive Waste Management 1989), this analysis assumes

Table 4.9. Resource Value of Buildings Sector Generic Quad of Source Fuels, 1987 and 2010

	Value, $ Millions ($1986)				
Year	Coal	Natural Gas	Petroleum	Yellowcake	Total
1987	423	559	308	20	1310
2010	803	1684	675	19	3181

that the spent fuel will be stored onsite (at least until a geologic repository or monitored retrievable storage facility is constructed) and selects the metal dry storage cask as the storage technology that utilities will adopt. This technology was chosen because it is proven and commercially available in the United States. The costs of metal casks are estimated to range from $55/kg to $105/kg of heavy metal (in 1988 dollars). This range was simply averaged for a cost of $80/kg and assumed to remain constant to 2010. Production of the generic quad of buildings energy yields about 36 metric tons of heavy metal (MTHM) in 1987 and 29 MTHM in 2010. This yields a storage cost of $3 million in 1987 and $2.3 million in 2010 for the spent nuclear fuel that contributed to the production of the generic quad of energy.

Because this estimate of storage costs does not include the handling and transportation costs involved in eventually sending the spent fuel to an intermediate or long-term storage facility, it understates the full cost of spent fuel storage.

4.3.2 Consumer Valuations

The value of the generic quad of energy may be viewed from the perspective of the owners and occupants of residential and commercial buildings who purchase the energy. The consumer's perspective presumably captures all of the above valuations, because the purchase, conversion, transportation, transmission, and disposal of the fuels is built into the rate at which he is billed.

The quad of generic source energy, as it is billed to the final consumer at the building site, is separated by the residential and commercial sectors to develop the consumer value, because the prices for the fuels in the two sectors are different. The *LREP* forecasts subdivide the delivered components of the generic quad between the residential and commercial sectors along with their respective fuel prices as shown in Table 4.10. It is important to note that these are average fuel prices. Economic theory holds that marginal fuel prices should ideally be nsed to value consumer

Table 4.10. Consumer Value of 1 Generic Quad, 1987 and 2010

			Residential		Commercial		
Year	Fuel	Total TBtu	TBtu	$1986/ MBtu	TBtu	$1986/ MBtu	Total Value, $ millions
1987	Petroleum	91	50.0	4.46	41.0	3.08	349
	Natural Gas	241	154.2	5.57	86.8	4.94	1288
	Electricity[(a)]	191	101.2	20.34	89.8	20.56	3905
						Total	**5542**
2010	Petroleum	56	24.1	12.39	31.9	10.03	619
	Natural Gas	194	114.5	11.28	79.5	10.80	2150
	Electricity[(a)]	207	114.3	23.52	92.7	23.41	4858
						Total	**7627**

(a) Electricity is expressed in TBtu delivered energy; conversion to source Btu may be accomplished by multiplying the 1987 quantity by 3.29 and the 2010 quantity by 3.43.

expenditures. However, *LREP* does not provide marginal prices. The coal and renewable fuels are not included in this valuation, because their prices were not available in the *LREP* and they constitute less than 9% of the site-delivered energy from the source quad. Of the estimated annual consumer value of $7.6 billion for 2010 derived from Table 4.10, about $4.3 billion is in the residential sector and $3.3 billion in the commercial sector.

The consumer value of these three fuel types is also developed per TBtu, as shown in Table 4.11. The values in millions of dollars per TBtu are shown for the commercial and residential sectors separately and for the two sectors combined on a weighted average basis.

4.3.3 Valuation Summary

In Table 4.12, the dollar valuations associated with the generic quad of buildings energy in 1987 and 2010 are summarized. The valuations are in current (1986/1987) dollars to facilitate comparisons. In interpreting these valuations, two caveats apply. First, it is not appropriate to total them, as they represent different ways of relating the economic value of the energy. Moreover, annual energy costs must not be added to investment costs. Second, the valuations do not contain all the costs associated with the generic quad; therefore, they represent the lower bound of the economic value.

Table 4.12 reveals that, from 1987 to 2010, the value of nuclear and coal electric generating capacity associated with the generic quad will increase, due to the increasing share of electricity in buildings sector energy use. The value of input fuels increases from 1987 to 2010, due to escalation in real fuel prices. Because the nuclear share of the generic quad is projected to remain virtually constant through time, the associated expense of decommissioning remains constant. Finally, the consumer expenditures associated with the generic quad are projected to increase from 1987 to 2010 by about 40%.

Table 4.11. Consumer Value per TBtu of Petroleum, Natural Gas, and Electricity, 1987 and 2010

		Value, $ Millions ($1986)		
Year	Fuel	Residential	Commercial	Combined
1987	Petroleum	4.46	3.08	3.84
	Natural Gas	5.57	4.94	5.34
	Electricity[a]	20.34	20.56	20.44
2010	Petroleum	12.39	10.03	11.05
	Natural Gas	11.28	10.80	11.08
	Electricity[a]	23.52	23.41	23.48

(a) Electricity prices are expressed in million dollars per TBtu delivered energy; conversion to value per TBtu source energy may be accomplished by multiplying the 1987 value by 0.304 and the 2010 value by 0.292.

Table 4.12. Summary of Economic Valuations Associated with 1 Generic Quad of Buildings Energy, Current Dollars (1986/1987)

Cost Components	Valuation, millions of dollars 1987	2010
Electric Generating Capacity	11,300	13,000
Nuclear Capacity Decommissioning	2,500	2,500
Annual Input Fuel Values	1,310	3,181
Storage of Spent Fuel	3	2
Annual Consumer Expenditures	5,542	7,627

Note: It is not appropriate to sum these valuations into one total.

The major valuations associated with the generic quad can be divided into three separate categories, **none of which is additive.** Societal investment costs include the initial expenditures for generation capacity, as well as the inevitable outlays for decommissioning nuclear plants and storing irradiated spent fuel. For 1987, these costs would total $13.8 billion in 1987 and about $15.5 billion in 2010, in current dollars. Note that these are **not** levelized costs. The annual "operating" cost to society of the generic quad is essentially the annual value of the source fuels. Finally, consumer expenditures for energy capitalize both types of expenditures in the rate at which consumers are billed.

5.0 Programmatic Application

The conversion factors documented in this report can be used to quantify the range of attributes associated with programs under development in DOE's Office of Building Technologies (OBT). Two illustrative examples are presented in this section. Both cases were selected from the *Energy Conservation Multi-Year Plan, 1990-1994* (Office of Conservation 1988). The first applies the generic quad conversion factors to the energy saving goal of the OBT research program; the second applies the fuel-specific factors to the lighting research program energy reduction target.

5.1 OBT Program Valuation

As shown in Table 4.1, the buildings sector is projected to consume 40.7 quads of energy in 2010. However, through the continued development and adoption of energy-efficient buildings technologies and practices, OBT projects that it is possible to reduce that level of consumption significantly. At "economically achievable" levels, that consumption could be reduced by 11.2 quads below projected levels; this would essentially hold buildings sector consumption constant at the 1987 level in the year 2010. At "technically achievable" levels, consumption could be reduced by 17.8 quads, which would reduce year 2010 levels about 20% below 1987 consumption.

Economically achievable levels are those "...that could be obtained should consumers adopt, at modest levels, currently available cost-effective technologies and anticipated technologies that are still under development." Technically achievable levels are those "...that are possible given full adoption of all known, potentially cost-effective conservation techniques, including those still under development at DOE." (Office of Conservation 1988, pp. 4-9 - 4-10).

The conversion factors for the generic quad developed in Section 4 are applied to the energy reduction quantities (11.2 quads and 17.8 quads) to yield a range of values for each attribute. The two energy savings are simply multiplied by the generic quad conversion factors developed earlier to provide the associated physical quantities of fuel inputs, fossil fuel emissions, spent nuclear fuel, and major economic costs. (The key reference table from which all else follows is Table 4.4 from Section 4.) In performing these calculations, the energy reductions are assumed to be achieved in a fuel-neutral sense, so that the fuel mix of the saved energy is identical to that supplied to the buildings sector as a whole. That is, energy efficiency is assumed to occur in terms of generic quads.

The results are presented in Table 5.1. The values listed under each column heading are the amounts by which the projected energy consumption, emissions, and costs for the buildings sector in 2010 would be reduced at the economically achievable and technically achievable levels defined above.

The combination of coal, natural gas, and petroleum accounts for nearly 75% of the energy reductions. The physical quantities of fuel can be put in perspective by comparing them to total projected consumption for the respective fuel types. The *LREP* forecast projects that in 2010, U.S. total coal consumption will amount to 1698 million short tons. This means that coal consumption would be reduced by about 14% at the economically achievable level and 22% at the technically achievable level. For natural gas, reductions of about 14% and 22% would also be achieved for the two reduction levels. Petroleum consumption reductions would range from 2% to 4%, respectively, for the economically and technically achievable levels.

Table 5.1. Decomposition of Office of Building Technologies Economically and Technically Achievable Energy Reduction Targets, 2010

	Economically Achievable (11.2 Quads)	Technically Achievable (17.8 Quads)
Energy Form (quadrillion Btu)		
Coal	5.06	8.05
Natural Gas	2.43	3.86
Petroleum	0.77	1.23
Nuclear	1.30	2.06
Hydroelectric	0.64	1.01
Renewables	1.00	1.58
Physical Quantities		
Coal (10^6 short tons)	239	379
Natural Gas (10^{12} ft^3)	2,352	3,738
Petroleum (10^6 bbl)	143	228
Nuclear (10^6 lb U_3O_8)	7.97	12.67
Byproducts		
CO_2 (10^{12} gc)	178	283
SO_2 (10^6 lb)	4,536	7,209
NO_x (10^6 lb of NO_2)	2,778	4,414
Spent Fuel (MTHM)	325	516
Major Economic Costs[(a)] (1986/1987 dollars)		
Electric Generating Plant		
Capacity (MW)	111,171	176,683
Capacity Investment (10^9 dollars)	146.0	231.0
Nuclear Plant Decommissioning (10^9 dollars)	28.0	44.5
Fuel Inputs (10^9 dollars)	35.7	56.7
Spent Fuel Storage (10^6 dollars)	22.4	35.6
Annual Consumer Value (10^9 dollars)	85.2	135.4

(a) The consumer value should not be totalled with the other values.

The reduction in environmental emissions associated with reduced energy consumption is shown for CO_2, SO_2, and NO_x. The year 2010 carbon emissions for the economic and technical reduction levels would reduce total U.S. emissions by 10% and 16%, respectively. With no change in emissions standards for SO_2 and NO_x, SO_2 emissions would be decreased by 9% and 14% below projected total U.S. emissions for the two respective reduction levels; NO_x emissions would reduce 4% and 7% below projected U.S. totals. (See Table 4.8 in Section 4.) In the case of more restrictive emissions levels, the SO_2 emissions reduction would range from 7% to 11% of the U.S. total for the two reduction levels; the NO_x emissions reduction would range from 2% to 4% of the U.S. total. Avoided discharges of radioactive spent fuel would range from 325 to 516 metric tons, respectively, for the economically and technically achievable cases.

A major avoided cost associated with the economic and technical energy reduction levels is the investment in new electric generating capacity, which ranges from 111 to 177 thousand megawatts for the respective cases. The avoided cost of this capacity plus the avoided expenses of nuclear plant decommissioning, fuel inputs, and spent fuel storage amounts to about $210 billion for the economically achievable reduction level and $333 billion for the technically achievable level. The reductions in petroleum consumption would likely result in reduced demand for oil imports and would improve the nation's merchandise trade balance by $7.5 billion and $12 billion for the economic and technical reduction levels, respectively. (See Table 4.9, Section 4.)

The consumer value of the energy provides an alternative economic measure that includes the fuel cost as well as the capital that is used in providing the energy to the consumer. The economically achievable reduction level of 11.2 quads would provide consumers with an additional $85 billion of disposable income in the year 2010.[a] Reductions at the technically achievable level would give consumers an additional $135 billion to spend on nonenergy goods and services. The consumer valuations should not be added to the other values, as this involves double counting. The energy bills paid by consumers include the total of the total annual operation and maintenance costs plus the annualized capital cost.

This analysis does not attempt to estimate the potential costs to society of achieving energy savings targets of the magnitude discussed here, because this is not a benefit-cost analysis. However, it is recognized that these costs are potentially large.

5.2 Lighting Program Valuation

The OBT lighting research and development program could reduce energy consumption projected for 2010 by 1.7 quads of primary electrical energy (Office of Conservation 1988). The development of the energy reductions associated with the lighting program focuses solely on electricity and its constituent fuels rather than the generic quad of Section 5.1. The key reference table is 4.2 instead of Table 4.4, used in the previous discussion. In essence, Table 4.2 presents a generic quad for "electricity-only" energy savings calculations. The decomposition of the energy for the lighting program is shown in Table 5.2. Table B.2 is used for the conversions to physical fuel quantities.

In this case, coal is the major primary fuel type; natural gas and petroleum are the smallest contributors. The reduction in coal use amounts to almost 3% of projected total U.S. consumption, with petroleum and natural gas reductions amounting to less than 1% of projected total U.S. consumption.

(a) Assuming that any increased program costs are not funded with increased taxes.

Table 5.2. Decomposition of Lighting Program Energy Reduction Target of 1.7 Quads by 2010

	Amount of Consumption Reduction
Energy Form (trillion Btu)	
Coal	1,083
Natural Gas	54
Petroleum	31
Nuclear	138
Hydroelectric	279
Renewables	112
Physical Quantities	
Coal (10^6 short tons)	51
Natural Gas (10^9 ft^3)	54
Petroleum (10^6 bbl)	5
Nuclear (10^3 lb U_3O_8)	847
Byproducts	
CO_2 (10^{12} gc)	29
SO_2 (10^6 lb)	975
NO_x (10^6 lb NO_2)	596
Spent Fuel (MTHM)	34
Major Economic Costs (1986/1987 dollars)	
Electric Generating Plant	
Capacity (MW)	21,452
Capacity Investment (10^9 dollars)	25.0
Nuclear Plant Decommissioning (10^9 dollars)	2.9
Fuel Inputs (10^9 dollars)	2.2
Spent Fuel Storage (10^6 dollars)	2.7
Annual Consumer Value (10^9 dollars)	11.7

The associated carbon emissions would account for less than 2% of projected U.S. total emissions. If emissions level requirements remain unchanged, SO_2 and NO_x emissions would amount to about 2% and 1% of U.S. total emissions. If more restrictive emissions requirements were implemented, the SO_2 and NO_x emissions levels would be 1.5% and 0.5% of the U.S. totals, respectively. Because the fuel type is electricity, the major economic cost is for the generating plant, amounting to about $25 billion. Alternatively, the annual cost of this energy to consumers is nearly $12 billion.

6.0 References

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Appendix A

Fuel Share Conversion Methodology

Appendix A

Fuel Share Conversion Methodology

This appendix contains the methodology used for calculating the buildings sector fuel shares for the historical and forecast periods. Along with the methodology, key assumptions are identified to enable replication of the analysis. The calculation of the fuel shares for energy consumed at the building site (direct or site energy) is described first. Next, the methodology used to develop the fuel shares for the indirect energy used to generate electricity is described. The summation of the direct and indirect fuel shares is presented last, providing the source energy fuel shares.

Direct Fuel Shares

The data and projections used to calculate the direct fuel shares are from two sources, *State Energy Data Report: Consumption Estimates 1960-1987* (Energy Information Administration 1989b), hereafter *SEDR*, and *Long Range Energy Projections to 2010* (Office of Policy, Planning and Analysis 1988), hereafter *LREP*. The *SEDR* is the source for 1960-1987 historical consumption data on buildings sector consumption of coal, natural gas, oil, and electricity. The *LREP* is the source for projected buildings sector consumption of coal, natural gas, oil, and electricity in 2000 and 2010, and also the source of the historical direct consumption of renewables for 1960-1987 and of the projected renewables consumption in 2000 and 2010. The reference case scenario is selected from the *LREP* for this analysis. The renewables data, which include solar, wind, and various kinds of biomass used at the building site (termed dispersed renewables), are distinguished from renewables, such as hydropower, geothermal, and biomass, used directly by utilities to generate electricity.

Calculating the direct fuel shares involves a number of steps. First, the total buildings sector consumption of coal, natural gas, oil, and electricity is the sum of the residential and commercial sector consumption of those fuels in the *SEDR*. The electricity data include sales to the consumers and system losses incurred in the generation, transmission, and distribution of electricity, as well as utility own use. Although such losses are not actually delivered to and consumed by utility customers, they are included in the total amount of energy used, because the production of delivered electricity entails such losses.

The *LREP* projections of buildings sector energy use for 2000 and 2010 are only for sales of delivered electricity (see Office of Policy, Planning and Analysis 1988, p. 3-32, Table 3-7) and do not include buildings sector-specific estimates of electrical system losses as does the *SEDR*. These losses are estimated using the implied generating efficiencies for the utility sector from the *LREP* (p. 3-29, Table 3-6) for 2000 and 2010. For example, *LREP* Table 3-6 shows the year 2000 electricity sector sales and losses to be 11.3 and 27.6 quads, respectively. The implied efficiency is therefore 11.3/(11.3 + 27.6) = 0.2905, or 29.05% and, in 2010, 29.23%. The inverse of this efficiency, when multiplied by buildings sector electricity sales, yields the associated primary equivalent in quads as shown in Table A.1.

The implied *LREP* generating efficiencies are consistent with the *SEDR* data. The *SEDR* indicates that between 1960 and 1987, conversion efficiencies ranged from 28.6% in 1960 to 30.4% in 1987, although the data do not reveal a

Table A.1. Direct Energy Consumption and Fuel Shares in the Buildings Sector, 1960 Through 1987, 2000, and 2010

	Consumption, TBtu					
Year	Coal	Natural Gas	Petroleum	Electricity	Renewables	Total
1960	980.4	4267.7	3492.8	4,292.5	600.0	13,633.4
1965	610.5	5502.6	3867.1	6,039.0	500.0	16,519.2
1970	370.5	7407.2	4306.3	9,570.2	400.0	22,054.2
1975	208.1	7580.3	3804.6	12,303.5	400.0	24,296.5
1980	147.7	7521.1	3035.4	14,951.2	800.0	26,455.4
1985	176.5	7069.4	2572.5	17,016.2	1000.0	27,834.6
1987	165.0	6919.3	2618.4	18,027.8	1000.0	28,730.5
2000	200.0	8300.0	2700.0	23,405.6	1300.0	35,905.6
2010	100.0	7900.0	2300.0	28,736.4	1700.0	40,736.4

	Shares, Percent[a]					
Year	Coal	Natural Gas	Petroleum	Electricity	Renewables	Total
1960	7.2	31.3	25.6	31.5	4.4	100
1965	3.7	33.3	23.4	36.6	3.0	100
1970	1.7	33.6	19.5	43.4	1.8	100
1975	0.9	31.2	15.7	50.6	1.6	100
1980	0.6	28.4	11.5	56.5	3.0	100
1985	0.6	25.4	9.2	61.1	3.6	100
1987	0.6	24.1	9.1	62.7	3.5	100
2000	0.6	23.1	7.5	65.2	3.6	100
2010	0.2	19.4	5.6	70.5	4.2	100

(a) Shares may not sum to 100% due to rounding.

consistent upward trend with time. The simple average over the period is about 29.4%. The generating efficiencies contained in *LREP* are consistent with the historical efficiencies.

The next step calculates the direct fuel shares on an annual basis for coal, gas, oil, electricity, and dispersed renewables. The direct fuel shares are simply the quantity of each fuel divided by the associated annual total energy consumption. The direct consumption by fuel type in trillion British thermal units (TBtu) and the share of the total by fuel type for the historical and forecast periods are shown in Table A.1. These data show that the electricity share for the buildings sector increased steadily from 1960 to 1987, and that it is projected to continue rising through 2010. The share of dispersed renewables decreased steadily from 1960 to 1975, then increased through 1985 and continues increasing to the year 2010. The increased shares of electricity and dispersed renewables are balanced by the shares of coal and oil, which fall steadily from 1960 to 2010, and of natural gas, which declines through 2010 after peaking in 1970.

Indirect Fuel Shares

Electricity is generated from a number of source fuels that include coal, petroleum, nuclear, hydro, and renewables. The electricity fuel share is decomposed into these source fuels to develop the indirect fuel shares. This is done in three steps. The first step is to develop a consistent series of data for the energy inputs to electric utilities. The second step is to calculate the share of each source energy input to total utility energy use. The final step is to multiply the utility input fuel shares by the direct primary electricity share (in Table A.1) for the buildings sector. This decomposes the direct electricity share into its respective energy sources.

The first step in estimating the indirect fuel shares is to ensure that the 2000 and 2010 projections are consistent in level of detail with the historical data series for the energy inputs to electric utilities. The 1960-1987 data are from the *SEDR* Table 17, "Estimates of Energy Input at Electric Utilities." The projections for 2000 and 2010 are from Table 3-6 and Table B-1 of the *LREP*. For oil, gas, coal, and nuclear, the *LREP* is consistent with the *SEDR*. That is, the historical data on oil, gas, coal, and nuclear inputs in Table 3-6 data are identical to those in the *SEDR*. However, in Table 3-6, the *LREP* aggregates all renewables (hydroelectric, geothermal, "other") into one category, whereas the *SEDR* provides estimates for each of these renewable sub-groups. Table B-1 of the *LREP* is referenced to provide the breakdown for hydro power and geothermal and other renewable fuel inputs for the 2000 and 2010 time periods.

For example, the "large hydro" and "small hydro" projections from Table B-1 are summed, then added to net imports of electricity (from Table 3-6) to produce a hydroelectric number that is defined consistently with the *SEDR*. The *SEDR* data include electricity imports with hydro production figures, presumably because the imports are Canadian hydro. The projections of "other" renewable supplies are obtained by subtracting the hydro contribution from the "Centralized Total" of Table B-1. The utility energy input data and fuel shares are shown in Table A.2.

The second step in calculating the indirect fuel shares is to derive the energy input shares for the utilities. These shares pertain to the energy supplied to utilities for distribution to the four sectors of the economy: residential, commercial, industrial, and transportation. The assumption is that the utility shares for the buildings sector are identical to the utility shares for all four sectors. That is, if, in 1987, 54.9% of electricity is coal-generated for the entire economy, then 54.9% is also coal-generated for the buildings sector.

The indirect fuel shares are then derived by multiplying the utility energy input shares (Table A.2) by the direct electricity shares for the buildings sector (Table A.1). This step decomposes the electricity share into the respective indirect fuel shares, shown in Table A.3. The indirect fuel shares in Table A.3 sum to the electricity share in Table A.1.

A specific example may be useful. Of each quad of primary energy supplied to the buildings sector in 1987, 62.7% was in the form of electricity (Table A.1), of which 54.9% was coal-fired (Table A.2). The resulting product provides that 34.4% is the total share of the generic quad that was "indirectly" supplied by coal to the buildings sector. This procedure was then repeated for the other utility input shares. Other fuel types do not have the level of associated losses that electricity has. Natural gas, the other major fuel type for the buildings sector, has estimated transmission and distribution losses of less than 2% in 1987 and 1988 (Energy Information Administration 1989a).

Summation of the Direct and Indirect Shares

The total contribution of each primary fuel supplied to the buildings sector simply involves adding the nonelectric direct shares from Table A.1 to the indirect shares of Table A.3. For example, in 1987, coal provided 0.6% of fuel consumed directly in the buildings sector and 34.4% of indirect consumption, for a total of

Table A.2. Electric Utility Energy Input Shares by Fuel Type, 1960 Through 1987, 2000, and 2010

	Energy Input, TBtu						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	4,226.6	1,785.1	552.7	1,618.0	6.0	2.3	8,190.7
1965	5,821.4	2,408.5	722.0	2,024.8	43.2	7.0	11,026.9
1970	7,228.0	4,047.6	2,117.3	2,620.1	239.3	15.0	16,267.3
1975	8,789.3	3,231.6	3,165.7	3,186.6	1,899.8	72.2	20,345.2
1980	12,157.9	3,803.6	2,633.6	3,084.7	2,739.2	114.3	24,533.3
1985	14,586.4	3,156.9	1,090.5	3,330.0	4,148.8	212.8	26,525.4
1987	15,114.8	2,933.7	1,256.9	3,054.5	4,046.5	244.5	27,550.9
2000	22,600.0	2,700.0	1,400.0	3,850.0	6,700.0	1,190.0	38,440.0
2010	31,400.0	1,600.0	900.0	3,980.0	8,100.0	3,290.0	49,270.0

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	51.6	21.8	6.7	19.8	0.1	0.0	100
1965	52.8	21.8	6.5	18.4	0.4	0.0	100
1970	44.4	24.9	13.0	16.1	1.5	0.1	100
1975	43.2	15.9	15.6	15.7	9.3	0.3	100
1980	49.6	15.5	10.7	12.6	11.2	0.4	100
1985	55.0	11.9	4.1	12.6	15.6	0.8	100
1987	54.9	10.6	4.6	11.1	18.0	0.9	100
2000	58.8	7.0	3.6	10.0	17.4	3.1	100
2010	63.7	3.2	1.8	8.1	16.4	6.6	100

(a) Shares may not sum to 100% due to rounding.

35.0%. Table A.4 provides the shares of primary fuels in the buildings sector.

The total share of coal increased steadily from 1970 to 1987 and is projected to increase to over 45% of energy supplied to the buildings sector by 2010. The share of nuclear power also steadily increased through 1987, although its share is projected to remain virtually flat thereafter. The share of natural gas declined from its 1970 peak and is projected to continue falling through 2010. Petroleum's share shows a steady decline from 1960 to 1985, although 1987 indicates that this trend may be reversing. Projections show petroleum nearly halving its 1987 share.

Table A.5 provides the "generic quad" of buildings sector energy for 1987 and 2010 using the source fuel shares from Table A.4 and converting them to TBtu equivalents. This generic quad is used throughout the report as a reference point for quantifying the major physical fuel resources, emissions, and economic values associated with buildings sector energy consumption.

Table A.3. Buildings Sector Indirect Fuel Shares, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]							
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Geo-thermal	Renew-ables	Total
1960	16.2	6.9	2.1	6.2	0.0	0.0	0.0	31.5
1965	19.3	8.0	2.4	6.7	0.1	0.0	0.0	36.6
1970	19.3	10.8	5.6	7.0	0.6	0.0	0.0	43.4
1975	21.9	8.0	7.9	7.9	4.7	0.2	0.0	50.6
1980	28.0	8.8	6.1	7.1	6.3	0.3	0.0	56.5
1985	33.6	7.3	2.5	7.7	9.6	0.5	0.0	61.1
1987	34.4	6.7	2.9	7.0	11.3	0.5	0.0	62.7
2000	38.3	4.6	2.4	6.5	11.4	1.2	0.9	65.2
2010	45.0	2.3	1.3	5.7	11.6	1.6	3.1	70.5

(a) Shares may not sum to 100% due to rounding.

Table A.4. Building Sector Fuel Shares by Source Fuel Type, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	23.4	38.2	27.7	6.2	0.0	4.4	100
1965	23.0	41.3	25.8	6.7	0.1	3.0	100
1970	21.0	44.4	25.2	7.0	0.6	1.8	100
1975	22.7	39.2	23.5	7.9	4.7	1.8	100
1980	28.6	37.2	17.5	7.1	6.3	3.3	100
1985	34.3	32.7	11.8	7.7	9.6	4.1	100
1987	35.0	30.8	12.0	7.0	11.3	4.0	100
2000	38.9	27.7	9.9	6.5	11.4	6.5	100
2010	45.2	21.7	6.9	5.7	11.6	8.9	100

(a) Shares may not sum to 100% due to rounding.

Table A.5. Generic Quad of Buildings Sector Source Fuels, 1987 and 2010

	TBtu					
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables
1987	350	308	120	70	113	40
2010	452	217	69	57	116	89

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Appendix B

Conversion to Physical Quantities

Appendix B

Conversion to Physical Quantities

The conversion of fuels from British thermal units and fuel shares to equivalent physical quantities is described in this appendix for coal, natural gas, oil, and nuclear power. Because no obvious physical equivalents for hydropower, and geothermal and renewables exist, no attempt is made to convert these fuel shares. For coal, natural gas, and oil, the methodology is simply to convert the direct and indirect shares for these fuels (Appendix A) into physical equivalents using conversion factors derived from the data in *State Energy Data Report: Consumption Estimates 1960-1967 (SEDR)* and projections in *Long Range Energy Projections to 2010 (LREP)* (Energy Information Administration 1989c; Office of Policy Planning and Analysis 1988). For nuclear power, information from *Commercial Nuclear Power 1989* (Energy Information Administration 1989b) and *World Nuclear Fuel Cycle Requirements 1989* (Energy Information Administration 1989d) is used to make the conversion from the nuclear fuel share to tons of U_3O_8 (yellowcake) and tons of spent fuel. These conversions are described separately in the final section of this appendix.

Conversion of Coal, Natural Gas, and Oil

The first step in the conversion process is to derive the physical quantity conversions for the direct and indirect use of coal, natural gas, and oil. The physical quantity data for 1960 through 1987 are drawn from *SEDR*. Projections for 2000 and 2010 are drawn from *LREP*. The *LREP* oil physical quantity data, expressed in millions of barrels per day, are multiplied by 365 days to obtain millions of barrels per year to be comparable to the *SEDR* data. The physical quantities for the fuel types are simply divided by their respective British thermal unit equivalents to obtain the physical quantities per TBtu of heat content.

For example, in developing the physical quantities for direct coal consumption in the buildings sector in 1987, the 7 million short tons (1 short ton = 2000 lb) of coal are divided by the associated 165 TBtu (Table A.1) to provide 42.424 thousand short tons of coal per TBtu. Table B.1 provides the direct consumption of physical quantities per TBtu for coal, gas, and oil. The physical quantities for coal and oil are derived by using the totals for these fuels rather than by specific fuel variety. The quantity of coal per TBtu is held constant at the 1987 level derived from *SEDR* because the *LREP* projections provide significantly lower quantities for the forecast periods, perhaps due to rounding errors.

Although the *SEDR* categorizes coal into bituminous and anthracite coal and oil into distillate, kerosene, and LPG, it is not considered worthwhile to derive separate conversion factors for these because most of the coal consumed directly is bituminous and most of the petroleum consumed directly is distillate. The added accuracy of using more disaggregate conversion factors is considered to be negligible. In addition, separate conversion factors could not have been derived for 2000 and 2010, since the *LREP* provides only total coal and oil data.

The procedure employed above to derive the direct physical quantities is replicated to derive the indirect physical quantities using the total physical quantity of fuels and British thermal units supplied to the utility sector. The physical quantities per TBtu for the fossil fuel inputs to electric utilities are shown in Table B.2. As with the direct physical quantity estimates, separate conversions for the different varieties of coal and oil consumed by utilities are not derived. Of the coal burned by utilities to generate electricity, 99.9% was bituminous in 1987. Of the petroleum burned, over 90% was heavy oil in 1987. The dominance of these fuels makes using separate conversion factors for anthracite coal and light oil a negligible gain in accuracy.

The final step is to develop a weighted average of the physical quantities of fossil fuel input per TBtu for the direct and indirect fuels combined and to multiply these by the TBtu composition of

Table B.1. Physical Quantities of Buildings Sector Direct Consumption of Fuel per TBtu, 1960 Through 1987, 2000, and 2010

	Consumption Quantity/TBtu		
Year	Coal, thousand short tons	Natural Gas, billion ft^3	Petroleum, thousand bbl
1960	41.8	966	179.5
1965	42.6	972	180.8
1970	43.2	977	185.1
1975	48.1	980	186.9
1980	47.4	979	182.8
1985	45.3	971	192.0
1987	42.4	972	190.6
2000	42.4	964	189.4
2010	42.4	962	190.6

Table B.2. Physical Quantities of Buildings Sector Indirect Consumption of Fuel per TBtu, 1960 Through 1987, 2000, and 2010

	Indirect Consumption Quantity/TBtu		
Year	Coal, thousand short tons	Natural Gas, billion ft^3	Petroleum, thousand bbl
1960	41.9	966	159.2
1965	42.1	964	159.3
1970	44.3	971	160.1
1975	46.2	977	159.8
1980	46.8	968	159.9
1985	47.6	964	160.5
1987	47.5	969	159.9
2000	47.4	963	156.5
2010	47.2	1000	162.3

the generic quad from Table A.5 to obtain the associated total physical quantities of fossil fuels. The weighted average quantities per TBtu are shown in Table B.3. The physical quantities comprising the generic quad are shown in Table B.4.

Conversion of Nuclear

This section provides the conversion of the nuclear power share into physical quantities of uranium ore concentrate and of spent nuclear fuel for 1987 and 2010. This discussion begins with a

Table B.3. Weighted Quantities of Buildings Sector Consumption of Fuel per TBtu, 1960 Through 1987, 2000, and 2010

	Weighted Consumption Quantity/TBtu		
Year	Coal, thousand short tons	Natural Gas, billion ft^3	Petroleum, thousand bbl
1960	47.9	966	178
1965	42.2	970	179
1970	44.2	976	180
1975	46.3	979	178
1980	46.8	976	175
1985	47.6	969	185
1987	47.4	971	183
2000	47.3	964	181
2010	47.2	966	185

Table B.4. Physical Quantities of Coal, Natural Gas, and Petroleum Comprising the Generic Quad of Buildings Sector Energy, 1960 Through 1987, 2000, and 2010

Year	Coal, million short tons	Natural Gas, trillion ft^3	Petroleum, million bbl
1960	11.6	369	49.3
1965	9.7	400	46.2
1970	9.3	433	45.4
1975	10.5	384	41.8
1980	13.4	363	30.6
1985	16.3	317	21.8
1987	16.6	299	22.0
2000	18.4	267	17.9
2010	21.3	210	12.8

brief description of the typical nuclear fuel cycle to provide a context for the subsequent analysis. The discussion proceeds with the data sources, assumptions, and procedure used for converting the nuclear power shares into physical quantities.

In the United States, the dominant type of nuclear reactor is the light-water reactor. Of the 107 operable reactors at the end of 1987, only two were not light-water reactors. The nuclear fuel cycle for a typical light-water reactor involves two distinct phases--a "front end" that comprises the steps necessary to prepare nuclear fuel for reactor operation, and a "back end" that involves the steps necessary to manage the highly radioactive spent fuel.

The "front end" begins with exploration for, and mining of, uranium-bearing ore deposits. In general, foreign ores are of a higher grade than U.S. ores, meaning that the content of uranium oxide, or U_3O_8, is higher. The next step is to crush and grind the ore and chemically extract the U_3O_8; this process is called "milling." The mill product, called uranium concentrate or "yellowcake," is then sold in pounds or short tons. Estimates of the reduced demand for yellowcake associated with 1 generic quad of buildings sector energy use are provided later in this section for 1987 and 2010.

The next step is to convert the yellowcake to uranium hexafluoride, UF_6, which is solid at room temperature, but at higher temperatures becomes gaseous. The UF_6 is then enriched to increase the concentration of ^{235}U and allow the nuclear reaction to be sustained. Finally, the enriched UF_6 is converted into fuel pellets of uranium dioxide, UO_2, which are then loaded into corrosion-resistant tubes, called "rods." The rods are then loaded into the reactor, and a controlled nuclear chain reaction initiated. The heat from this reaction is carried away by water, which, as steam, passes to a turbine-generator where electricity is generated.

When the declining concentration of ^{235}U reaches the point when the reaction can no longer be sustained, the reactor is shut down and refueled. This is the "back end" of the nuclear fuel cycle. Approximately 25% to 30% of the fuel is removed during refueling and replaced with fresh fuel. The spent fuel that is removed is placed in an onsite storage pool for cooling, after which it is either sent to be reprocessed or stored. Currently, much of the spent fuel is being temporarily stored at the reactor site until a long-term geologic repository is available to receive the spent fuel.

This analysis presents estimates for 1987 and 2010 of the required quantities of yellowcake and spent fuel that are associated with the generic quad of buildings sector energy consumption. *Commercial Nuclear Power 1989* (*Commercial Nuclear* hereafter) presents three supply scenarios of nuclear capacity growth out to 2020. *World Nuclear Fuel Cycle Requirements 1989* (*Fuel Cycle* hereafter) uses these three scenarios to develop projected requirements for the yellowcake and the associated discharges of spent fuel, also out to 2020.

The first task is to select the scenario that is most consistent with the *LREP* nuclear powerprojections used in this analysis. The nuclear-fueled electricity generation from *Commercial Nuclear* is provided in net terawatt-hours (TWh) of delivered electricity (Energy Information Administration 1989b, p. 14, Table 8). (One terawatt-hour is equivalent to one billion kilowatt-hours.) Terawatt-hours are converted to primary energy quads by multiplying the heat content of a kilowatt-hour, 3412 Btu/kWh, and the inverse of the conversion efficiency, which in this report (Appendix A) is 30.4% for 1987 and 29.2% for 2010. Using the 1987 efficiency, the multiplier to convert to primary quads is therefore 11,224 Btu/kWh and 11,685 Btu/kWh for 2010.

Of the three cases presented in *Commercial Nuclear*, the Upper Reference Case is selected for use in this report, as it projects 8.89 QBtu of nuclear fueled primary energy in 2010, about 10% greater than the *LREP* projection of 8.1 QBtu. The Lower Reference Case, by contrast, is 15% lower. The Upper Reference case numbers are produced from a long-term aggregated model that derives nuclear generation requirements as a share of delivered energy, whereas the Lower Reference case is a hybrid approach.

Yellowcake Quantities

The next step develops the ratios of yellowcake input per TBtu of primary nuclear energy. According to Table 2 of *Fuel Cycle*, (p. 5) the yellowcake requirements for the Upper Reference Case are 38.2 and 54.6 million pounds of U_3O_8 equivalent in 1989 and 2010, respectively. Yellowcake fuel cycle requirements are not provided for 1987, so it is not possible to develop an estimate of yellowcake requirements per TBtu with 1987 data. It is not accurate to use the yellowcake production number for 1987 from the *Annual Energy Review* (Energy Information Administration 1989a) because yellowcake production and requirements are not necessarily equal because of inventory buildup and reductions. This analysis develops the yellowcake/TBtu primary energy ratio using the commercial nuclear generation data for 1988 and the 1989 uranium requirements from *World Nuclear* and assumes this is a reasonable approximation for 1987.

The information used to develop the ratio of yellowcake per TBtu is shown in Table B.5. The quantities of yellowcake per TBtu of the primary fuel input are projected to be roughly constant between 1988 to 2010. From the generic quad (Table A.5), nuclear energy contributes 113 and 116 TBtu of the primary fuel for 1987 and 2010, respectively. Applying the yellowcake requirements per TBtu to the nuclear contribution provides the quantities of yellowcake input associated with the generic quad for the two years as shown in Table B.6. It should be noted again that the 1987 result was achieved using the 1988/1989 yellowcake/TBtu ratio of Table B.5, due to the lack of data on 1987 yellowcake requirements.

Table B.5. Yellowcake Fuel Requirements, Associated Primary Energy, and Ratio of Yellowcake per TBtu, 1988 and 2010

Year	Yellowcake, million lb	Primary Energy, TBtu	Yellowcake/TBtu, thousand lb
1988/1989	38.2	5915	6.46
2010	54.6	8892	6.14

Table B.6. Quantity of Yellowcake Associated with the Generic Quad of Buildings Sector Energy, 1987[(a)] and 2010

Year	Yellowcake, thousand lb
1987	729
2010	712

(a) Due to data constraints, the 1987 yellowcake estimate was derived from the 1988/1989 yellowcake/TBtu ratio.

Spent Fuel Quantities

Spent fuel is usually measured in metric tons of heavy metal (MTHM). The discharges of spent fuel for the *Fuel Cycle* Upper Reference Case are estimated at 1900 MTHM per year from 1989 through 1995 and 2200 MTHM per year from 2006 to 2010 (p. 8, Table 5). The spent fuel, associated primary energy, and the spent fuel per TBtu for 1988 and 2010 are shown in Table B.7. To maintain consistency with the calculation for yellowcake requirements, the associated nuclear primary energy for 1988 from *Commercial Nuclear* is used to develop the ratio of spent fuel per TBtu.

The final step is to develop the quantity of spent fuel associated with the nuclear contribution of the generic quad of energy. This calculation is the product of the spent fuel per TBtu and the TBtu quantity of nuclear energy per generic quad for the target years. As with yellowcake, the 1988/1989 spent fuel/TBtu ratio is applied to derive the 1987 estimate of spent fuel, on the assumption that the 1987 and 1988/1989 ratios are reasonably close. As shown in Table B.8, the quantity of spent fuel associated with a quad of buildings sector energy use is expected to decrease by about 20% over the time period.

Table B.7. Spent Nuclear Fuel, Associated Primary Energy, and Ratio of Spent Fuel per TBtu, 1988 and 2010

Year	Spent Fuel, MTHM	Primary Energy, TBtu	Spent Fuel/TBtu, MTHM
1988	1900	5915	0.321
2010	2200	8892	0.247

Table B.8. Quantity of Spent Fuel Associated with the Generic Quad of Buildings Sector Energy, 1987[(a)] and 2010

Year	Spent Fuel, MTHM
1987	36.3
2010	28.7

(a) Due to data constraints, the 1987 yellowcake estimate was derived from the 1988/1989 spent fuel/TBtu ratio.

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Appendix C

Emission Conversions

Appendix C

Emission Conversions

The conversion from the Btu quantities of coal, natural gas, and petroleum to emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) is described in this appendix. Comparable emissions estimates are not developed for combustible renewables for two reasons: 1) small quantities are consumed in the buildings sector and 2) disaggregate estimates of the quantities of combustibles are not available in the *State Energy Data Report (SEDR)* (Energy Information Administration 1989) or *Long Range Energy Projections to 2010 (LREP)* (Office of Policy, Planning and Analysis 1988).

CO_2 Conversions

The development of CO_2 emissions is based upon *A Preliminary Analysis of U.S. CO_2 Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010* (*CO_2 Emissions*) (Edmonds et al. 1989). Carbon dioxide emissions are developed per TBtu and for the generic quad of buildings sector energy for coal, natural gas, and petroleum.

The emission of CO_2 is a byproduct of the oxidation that occurs during fossil fuel combustion. Two technology-based alternatives to reduce CO_2 emissions are to remove the carbon from the fuels before combustion or to remove it from the exhaust stream. For this analysis, neither of these alternatives is considered, as there is no current policy action under development that would require CO_2 removal. A third alternative to reducing CO_2 emissions is to substitute fuels with low or no emissions for those with higher emissions. Fuel substitution is also not considered, as this analysis focuses on the generic quad for current consumption and the projections to 2010 from *LREP*.

The average emission coefficients of CO_2 in grams of carbon (gc) per TBtu are shown in Table C.1.[a] Coal has the highest coefficient, with 25.1 billion grams of carbon released per TBtu of heat content; natural gas is the lowest, with about 14.5 billion grams/TBtu.

The average emissions coefficients are applied to the Btu quantities of the three fossil fuels that make up the generic quad from Table A.5 to develop the total CO_2 emissions that are associated with the generic quad of energy as shown in Table C.2. For example, in the year 2010, the generic quad of energy is projected to contain 452 TBtu of coal-supplied energy, which suggests that coal will contribute 11.35 trillion grams of carbon to the generic quad total of 15.89 trillion grams of carbon.

Table C.1. Average CO_2 Emission Coefficients per TBtu for Coal, Natural Gas, and Petroleum

Fuel	Average Emission, billion gc
Coal	25.109
Natural gas	14.454
Petroleum	20.256

(a) In the literature on CO_2 emissions, it is the convention to state emissions in grams of carbon, which convert to CO_2 in the atmosphere.

Table C.2. CO_2 Emissions by Fuel Type and Total for the Buildings Sector Generic Quad of Energy, 1987 and 2010

	Emission, trillion gc			
Year	Coal	Natural Gas	Petroleum	Total
1987	8.79	4.45	2.43	15.67
2010	11.35	3.14	1.40	15.89

To put the quantities of carbon emissions in perspective, the estimated global carbon emissions were 5.2 petagrams (PgC, 10^{15} grams of carbon) in 1985, of which the estimated U.S. contribution was 1.25 PgC (24%) and the buildings sector contribution was 0.42 PgC (8%). The amount of carbon in the generic quad for 1985 was approximately 0.3% of the world total, 1.3% of the U.S. total, and 3.7% of the buildings sector total. Projected carbon emissions for 2010 are not available for the world, but are 1.73 PgC for the United States and 0.6 PgC for the buildings sector. The quantity of carbon in the generic quad accounts for about 0.9% of the estimated U.S. emissions and 2.7% of the total buildings sector emissions in 2010.

In both 1985 and 2010, the share of total emissions associated with the generic quad is nearly identical to its share of global and U.S. energy consumption, as shown in Table C.3.

SO_2 and NO_x Conversions

The development of SO_2 and NO_x emissions is based upon *Interim Assessment: The Causes and Effects of Acidic Deposition. Volume II - Emissions and Controls* (National Acid Precipitation Assessment Program [NAPAP] undated). This document provided information on historical and projected emissions of SO_2, NO_x, and volatile organic compounds from man-made and natural

Table C.3. Comparability of Buildings Sector Shares of Carbon Emissions and Energy Consumption

	Carbon Emissions, %			Energy Consumption, %		
Year	Global	U.S.	Buildings Sector	Global	U.S.	Buildings Sector
1985	0.3	1.3	3.7	0.3	1.3	3.6
2010	--(a)	0.9	2.7	--(a)	0.9	2.5

(a) Projection not available.

sources, as well as a description of alternative emission control technologies.

The estimated quantities of SO_2 and NO_x were developed for the generic quad of energy for only coal-fired electric generating plants. This somewhat restricted quantification was chosen for the following reasons:

- In 1980, approximately 62% of total SO_2 emissions was accounted for by coal-fired power plants. Other fossil fuel-fired power plants provided about 5% of the total, direct residential and commercial fossil fuel consumption provided 4% of the total emissions, and industrial and transportation sector fossil fuel consumption provided about 29% of total SO_2 emissions. In 1985, coal-fired power plants' share of total estimated CO_2 emissions (21.2 million metric tons) increased to approximately 67%. The increasing importance of coal-fired emissions and the decreasing use of oil and coal at the building site is the basis for focusing on the former.
- The total estimated U.S. NO_x emissions in 1985 was 19.3 million metric tons of NO_2,[a] of which almost 33% (6.3 million metric tons) was provided by fossil-fueled power plants. Coal was the dominant fuel source, providing nearly 78% of electric utility fossil fuel input. In addition, the increase in NO_x emissions over the 1975-85 decade was driven entirely by the dramatic rise in utility coal use. The NAPAP source also combines buildings fuel use with aircraft, railroads, vessels, off-highway vehicles, and industrial processes in an "Other" category, and does not provide more disaggregate detail.

Total SO_2 emissions decreased at an annual rate of 1.9% (from 25.8 to 21.2 million metric tons) for the United States as a whole from 1975 to 1985 and at an annual rate of 0.8% (from 15.4 to 14.2 million metric tons) for the coal-fired electric utility sector. At the same time, electric utility coal consumption increased from 406 to694 short tons (*SEDR*), an annual increase of 5.5%. The decrease in emissions is largely the result of control technologies brought about by the New Source Performance Standards (NSPS) and by the increased use of low-sulfur coal. The New Source Performance Standards were established as part of the Clean Air Act to set emissions ceilings for new power plants. As such, the 1971 NSPS have affected new capacity coming on line between 1972-1980, while the revised 1979 NSPS have affected capacity in the 1980s. It is important to note that the NSPS do not pertain to plants that were on line before the standards were promulgated.

The base case projection in the NAPAP *Interim Assessment*, assuming no further restriction in the NSPS requirement and no penetration of improved technology, is that utility sector SO_2 emissions from coal-fired plants will remain nearly constant through 2010 and then will begin to decline as pre-NSPS plants are retired. In conjunction, total U.S. SO_2 emissions are expected to increase to about 23 million metric tons per year by 2010, which provides that the utility share of total will remain constant at about 65%. A scenario providing a more restrictive NSPS requirement would result in a decrease of about 1 million metric tons of utility-generated SO_2 emissions by 2010 (*Interim Assessment*, pp. 3-17 to p. 3-18, and Figure 3-8).

Total U.S. NO_x emissions increased about 0.4% per year from 1975 to 1985, from 18.6 to 19.3 million metric tons. For the utility sector, the annual rate of increase was about 2.8%, from 4.8 to 6.3 million metric tons. Of the four sectors identified in the *Interim Assessment* (highway vehicles, power plants, industrial, and other), the utility sector was the only one showing an increase in NO_x emissions, and this increase was driven entirely by the rise in coal used over the period.

(a) The convention in the acidic deposition literature is to state NO_x emissions in tons of NO_2. Most anthropogenic nitrogen oxides are emitted as nitric oxide; however, NO is usually quickly converted to NO_2 in the atmosphere.

Oil use fell, and natural gas use remained constant from 1975 to 1985. Emissions of utility-generated NO_2 are projected to increase to about 9 million metric tons by 2010 because the NSPS requirements for NO_x emissions do not require as large a percentage reduction as for SO_2 emissions, and the number of power plants is projected to increase. At the same time, total U.S. NO_x emissions are expected to increase to nearly 27 million metric tons per year in 2010, which provides that the utility sector share will remain constant at 33%. The scenario providing for more restrictive NSPS requirements shows NO_2 emissions increasing less rapidly, reaching a level of about 8 million metric tons by 2010 (*Interim Assessment*, p. 3-18, Figure 3-8).

The revised NSPS 1979 requirement limits SO_2 emissions to a ceiling of 0.6 lb/million Btu (MBtu) of heat content for low-sulfur coals, increasing to 1.2 lb/MBtu for higher-sulfur content coals. This analysis develops two SO_2 emissions scenarios for 2010 that are consistent with NAPAP's projections of future SO_2 emissions (*Interim Assessment*, Figure 3-3 and Figure 3-8). The first scenario assumes continuation of the current NSPS to 2010 with no tightening of the standards. This analysis handled this assumption by assuming that the emissions in 2010 are limited to 0.9 lb/MBtu, which is the simple average of the low- and high-sulfur rates. The coal data and information from *SEDR* and *LREP* do not provide information on different sulfur content coals, so it was not possible to develop a weighted average emissions factor. (For comparison, it is worth noting that the emissions rate, averaging across all coal-fired capacity, was 1.9 lb/MBtu in 1987.) The second scenario, based on a sensitivity analysis in NAPAP for SO_2 emissions from tightening the NSPS, assumes that in 2010 the high-sulfur coal requirement remains at 1.2 lb/MBtu but that the low-sulfur coal requirement tightens to 0.15 lb/MBtu. Taking the simple average of these rates yields 0.68 lb/MBtu. These emission quantities translate to 900,000 and 680,000 lb/TBtu for the current NSPS and "higher compliance" scenarios, respectively.

A similar approach was taken for NO_x emissions from coal-fired power plants, and two NAPAP scenarios were assessed. The first scenario assumes continuation of the current NSPS regulations for NO_x emissions. Current NSPS require ceilings of 0.6 lb and 0.5 lb/MBtu for bituminous and subbituminous coals, respectively. (By comparison, emissions of NO_2, averaging across all coal-fired capacity, were about 0.89 lb/MBtu in 1987.) A simple average of the coal types was taken, i.e., 0.55 lb/MBtu, as information was not available in *SEDR* and *LREP* on coal types to develop a weighted average emissions factor. The second scenario assumes that the NSPS requirements for NO_x emissions are tightened, and would be set to achieve a 65% reduction in potential emissions. Unlike SO_2, NAPAP did not also provide an emissions ceiling for NO_x emissions. However, according to one of the principal authors of Chapter 3 of the *Interim Assessment*, a ceiling of about 0.3 lb/MBtu would approximately achieve such a 65% reduction, and would also be consistent with currently available NO_x control technologies.[a] These emission rates translate to 550,000 and 300,000 lb/TBtu for the current NSPS and "higher compliance" NSPS scenarios, respectively.

The emissions of SO_2 and NO_x developed for the generic quad for 1987 and 2010 are shown in Table C.4 for the current NSPS and the "higher-compliance" scenarios. For 1987, the emissions associated with the generic quad are developed from the emissions rates when averaged across all coal capacity, which includes both "clean" NSPS and "dirty" pre-NSPS plants. These rates are, by definition, higher than the NSPS ceiling limits. By contrast, in 2010 many more coal plants are NSPS-regulated, due to the retirement of older capacity, so the emissions rate averages across all plants will be considerably lower.

(a) Phone conversation with Dave G. Streets, Argonne National Laboratory, June 6, 1990.

Table C.4. Generic Quad of Energy SO_2 and NO_2 Emissions for NSPS-Based and High-Compliance Scenarios, 1987 and 2010

	SO_2 (million lb)		NO_x (million lb NO_2)	
Year	Current NSPS	High-Compliance	Current NSPS	High-Compliance
1987	654	N/A	310	N/A
2010	405	304	248	135

The quantities shown in Table C.4 are the product of the pounds per TBtu and the TBtu contribution of utility coal (from Table A.3) to the generic quad of energy. For example, the product of the 2010 current NSPS SO_2 emissions level of 900,000 lb/TBtu and the 450 TBtu of coal consumption yields SO_2 emissions of 405 million lb. Under the high-compliance scenario, the associated emissions would drop to about 304 million lb.

The share of total U.S. SO_2 and NO_x emissions associated with the generic quad of energy in 1985 was approximately 1.5% and 0.7%, respectively. For 2010, SO_2 emissions associated with the generic quad are projected to be about 0.8% for the NSPS scenario and about 0.6% for the high-compliance scenario. The share of total NO_x emissions in 2010 associated with the generic quad is projected to be about 0.4% for the NSPS scenario and 0.2% for the high-compliance scenario.

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Appendix D

Economic Valuations

Appendix D

Economic Valuations

The economic valuations of the generic quad of energy are presented in this appendix from two perspectives. The first includes the initial investment for the electric generating resource, the value of the annual fuel input, and the projected spent fuel storage costs in the case of nuclear fuel, as well as the projected decommissioning costs for nuclear generating plants. The second perspective is the annual value of the 1 quad of energy to consumers as fuel costs. This perspective includes the amortized value of the capital investments to provide the energy, as well as the annual fuel costs.

The two valuations are useful as alternative ways of viewing the value of providing the energy--total investment requirement compared to the annual "mortgage" payment. However, it should be recognized that they are neither comparable nor additive.

The first section details the conversions for translating the electricity component of the 1 quad of energy to coal and nuclear generating capacity and the value of this capacity. Included in this section is the estimated cost of decommissioning the nuclear generating capacity at the end of its useful life. The next section provides the annual value of the source fuels that comprise the generic quad of energy. This value is expressed in terms of the wholesale or commodity trading price of the fuel resource. Also included in this section is the projected value of storing the spent nuclear fuel. The final section provides the annual value of the delivered energy to consumers.

Electricity Generating Capacity Requirements and Values

This section develops the conversions to translate delivered electricity to generating capacity needs. An examination of current capacity (stated in terms of summer capability) by major type of generation from *Historical Plant Costs 1987* shows the approximate shares of the 1987 total existing capacity of 674,144 MW to be distributed by generating equipment type as follows: fossil-steam, 65.0%; gas-turbine, 6.5%; hydroelectric, 13.3%; and nuclear, 13.9% (Energy Information Administration 1989b). The fossil-steam capacity is approximately 80% coal burning, with the remainder supplied by oil and natural gas. These shares correspond reasonably closely to the 1987 fuel share inputs, when accounting for capacity factors, to electric utilities developed in Table A.2 of Appendix A.

The fraction of electricity generating capacity that is coal-fired is projected to increase even further in the future. Table A.2 (Appendix A) shows the coal fuel share, excluding other fossil, increasing to nearly 64% in 2010, while nuclear's share decreases slightly to about 16% in the year 2010. Coal energy input increases by about 16,300 TBtu from 1987 to 2010, and nuclear increases by about 3,200 TBtu. This implies that, of the combined coal and nuclear capacity additions, approximately 84% will be coal and 16% nuclear. The quantities of natural gas and petroleum fuel input to electric utilities are projected to decrease, implying that capacity additions for these fuel types will be small, if they occur at all. While hydro and renewables capacity are both projected to increase to 2010, this analysis does not focus on these fuels.

Based upon the high current and projected shares of electricity generating capacity and capacity additions that are coal and nuclear, the conversion factors for translating delivered electricity to units of capacity were developed only for coal and nuclear fuel capacity.

Electrical Energy to Capacity Conversion Factors

The methodology for developing conversion factors to translate delivered electrical energy (in Btu) to units of electrical generating capacity (in kW) is developed here. The formula for this conversion is expressed as

kW Generating Capacity = TBtu Delivered Electricity/(3412 Btu/kWh)/8760 hr/Capacity Factor

The key assumption in this formula is the value chosen for the projected capacity factor, which reflects the utilization of the generating plant. Values typically used in energy analyses are in the range of 60% to 70%. Actual capacity factors for nuclear, reported in *Annual Energy Review 1988*, averaged about 58% over the 1982-1988 period (Energy Information Administration 1989a). Capacity factors for coal-fired plants in 1986 and 1987 were between 56% and 57% (*Historical Plant Costs 1986* and *1987*). This analysis uses capacity factors of 60% and 55% for nuclear and coal, respectively.

The sensitivity of the conversion is illustrated for 100 TBtu of delivered electrical energy for the capacity factors as follows:

Fuel Type/Capacity Factor		Required kW Capacity
Coal	0.55	6,083,089
Nuclear	0.60	5,576,165

The difference of 506 thousand kW of capacity due to the selection of capacity factor value is important. It is equivalent to about one 500-MW coal-fueled power plant..

For 1987, 344 TBtu of coal-based input energy (Table A.3) is about 105 TBtu of delivered electricity, which converts using the above formula to about 6,387,000 kW of coal-fueled capacity. The 113 TBtu of nuclear-based input energy is about 34 TBtu of delivered electricity, which converts to about 1,896,000 kW of nuclear generating capacity. The calculations for 2010 indicate that the respective coal and nuclear energy inputs of 450 and 116 TBtu (Table A.3) are about 132 and 34 TBtu of delivered electricity, which convert to about 8,030,000 and 1,896,000 kW of capacity. These are the coal- and nuclear-fueled electricity capacity requirements that contribute to the generic quad of energy in 1987 and 2010.

Capacity Value

Estimates of the capital cost of installed generating capacity vary substantially. Recent experience for coal-fueled capacity range from $593/kW to $1935/kW for the period 1982 to 1987 in 1987 dollars (Energy Information Administration 1989b). These compare to values ranging from $1210/kW to $1760/kW assumed for load forecasting purposes in the Pacific Northwest (Northwest Power Planning Council 1989).

Experience with nuclear capacity additions is more varied for the recent past, ranging from $1229/kW to $4443/kW for the period 1982 to 1987 (in 1987$) (Energy Information Administration 1989b).

For this discussion, values of $1000/kW and $2600/kW are used for coal and nuclear capacity additions in 1987 dollars. The cost per kilowatt of installed coal capacity is the capacity-weighted average from 18 coal plants completed in 1982 through 1987 (Energy Information Administration 1989b). The cost per kilowatt of installed nuclear capacity is the capacity-weighted average from 18 nuclear plants that came on line over the 1982-1987 period (Energy Information Administration 1989b). Included in these capital costs are expenditures for land, land rights, structures, improvements, and equipment. The calculations in this section show that combined coal and nuclear electric generating capacity of 8,283,000 kW and 9,926,000 kW associated with the generic quad of source energy in the years 1987 and 2010 have a capital investment value of approximately $11.3 billion and $13.0 billion in current dollars for the respective years.

Nuclear Capacity Decommissioning Value

Empirical information on the costs of decommissioning a large nuclear plant does not currently exist, because no large facility has yet been decommissioned anywhere in the world. As such, estimates of future decommissioning costs from a range of reports show a very wide dispersion, from 5% to 200% of the original capital cost of construction. Since the average construction cost of 13 nuclear plants that came on line between 1982 and 1986 was $3.7 billion (in 1987 dollars), decommissioning costs for these plants could range from $0.19 to $7.4 billion based on the previous range of estimates (in 1987 dollars). In this context, it is illustrative to note that in 1987, California's Public Utility Commission ruled that Pacific Gas and Electric must set aside $3.89 billion for dismantling its Diablo Canyon reactor, which is about 72% of the initial investment outlay of $5.40 billion. In addition, decommissioning of DOE's small (72-MW) Shippingport plant is expected to run about $1136 per kW (1985 dollars). The cost of constructing nuclear capacity in the 1980s was $2600 (1987 dollars). Expressing Shippingport's decommissioning costs as a percentage of the current investment cost yields a figure around 45%.

It is apparent from the decommissioning literature that no one really knows what it will cost to decommission a large (1000-MW) nuclear facility. There are many uncertain factors. The future regulatory climate could tighten considerably, raising the cost of decommissioning. In addition, the issue of projecting costs accurately for long-term projects has frequently vexed policymakers, and rarely have cost estimates been too high. On the other hand, learning curve effects could yield important benefits, although it is hard to conceive of a 1000-MW, highly radioactive nuclear plant being decommissioned for less than a quarter of a billion dollars. Given all this uncertainty, this report uses a decommissioning cost that is 50% of the initial investment cost of $2600/kW. This is simply a rough average of the lowest decommissioning figure available and one equaling 100% of the investment cost. For the nuclear capacity associated with the generic quad in 1987, the decommissioning costs would therefore be about $2.5 billion (in 1987 dollars); in 2010, the costs would be the same.

Source Fuel Valuations

This section provides the valuations of the source fuels or primary energy that comprise the one quad of generic energy and, in the case of the nuclear fuel share, the fuel valuation includes the projected cost of storage and disposal of the spent fuel. The value of the fossil fuel inputs provided in the first subsection is expressed in terms of the wholesale market costs, such as the commonly referenced dollar price per barrel of oil. The second subsection provides the projected cost of uranium concentrate (yellowcake) requirements for the nuclear share of the generic quad. The third subsection provides the projected cost of at-reactor storage of the spent fuel associated with the generic quad.

Source Fossil Fuel Valuation

The value of the source fuel inputs is developed for coal, natural gas, and petroleum for 1987 and 2010. The value is stated in 1986 dollars and is based upon the resource cost of these fuels in *LREP* (Office of Policy, Planning and Analysis 1988, Table 3-3, p. 3-13). The calculation is the product of the physical quantity of the fuel to the generic quad (Table B.4) multiplied by the resource price, as shown in Table D.1. The resource prices from the *LREP* are stated in 1986 estimated dollars rather than in 1987 dollars. However, since the rate of inflation from 1986 to 1987 was 3%, this is not a significant understatement. This calculation shows the total value of the fossil fuel inputs for 1987 and 2010 to be about $1.3 billion and $3.2 billion, respectively (in 1986 dollars).

Current imports of these fuel types vary. Petroleum is the highest, with nearly 40% of 1987 U.S. consumption accounted for by imports. Approximately 5% of natural gas is imported, and the United States is a net exporter of coal. Given the level of petroleum imports, it is reasonable to assume that the oil comprising the generic quad of buildings sector energy was imported and accounted for about $308 million of the 1987 U.S. merchandise trade deficit, and will increase to $675 million in 2010.

Uranium Concentrate Valuation

The purpose of this section is to place an approximate economic value on the uranium concentrate associated with the nuclear share of the generic quad of buildings sector energy consumption. Table B.6 of Appendix B shows that the yellowcake requirements for the generic quad of buildings sector consumption are 729 thousand and 712 thousand pounds for 1987 and 2010, respectively.

Table D.1. Resource Value[(a)] of Buildings Sector Generic Quad of Source Fuels, 1987 and 2010

	Coal			Natural Gas		
Year	Quantity, million short tons	Cost, $/ton	Value, $ million	Quantity, trillion ft^3	Cost, $/million ft^3	Value, $ million
1987	16.6	25.46	423	299	1.87	559
2010	21.3	37.70	803	210	8.02	1,684

	Petroleum			Yellowcake			
Year	Quantity, million barrels	Cost $/barrel	Value, $ million	Quantity, thousand pounds	Cost, $/lb	Value, $ million	TOTAL VALUE, $ million
1987	22.0	13.98	308	729	27.00	20	1,310
2010	12.8	52.70	675	712	27.00	19	3,181

(a) Resource value is expressed in terms of 1986 dollars.

The valuation of the yellowcake, which is imported, is more complex than for petroleum because domestic sources of supply are 40% to 50% more expensive than foreign supplies, whereas a world oil price exists. The average price per pound for domestic and imported uranium oxide is shown in Table D.2 for 1983 through 1987. These prices multiplied by the yellowcake quantities required by the generic quad provide the total value of the yellowcake for 1987 and 2010, as shown in Table D.3 for domestic and foreign sources of supply. The source for the yellowcake prices, *Uranium Industry Annual 1988* (Energy Information Administration 1989c), does not provide projections of future prices, so the total value was calculated assuming that the 1987 per unit price remains constant through 2010.

In 1987, the U.S. nuclear industry imported 51% of its yellowcake. Of that amount, 98% was from Canadian suppliers, according to *Uranium Industry Annual*. Import commitments for delivery from 1988 to beyond 2000 are expected to be 67% Canadian and 33% Australian. Given the large share comprised by imports and the sources of supply, it is likely that a large share of the supply will continue to be met by imports.

The value of the uranium from Table D.3 to use in evaluating the generic quad is dependent upon the source of supply that a reduction in demand would impact. In the case of petroleum, the price for both sources is the same, i.e., there isyellowcake, and it is unlikely that domestic suppliers would be "protected," given the recent free trade agreement signed with Canada. Therefore, this analysis assumes that the demand reduction associated with 1 quad of buildings sector energy conservation would affect domestic supply, and the domestic yellowcake fuel price is used to value the yellowcake (Table D.1).

Table D.2. Average Prices for Uranium Oxide, 1983-1987

	Average Price, \$/lb U_3O_8				
	1983	1984	1985	1986	1987
Domestic	38.21	32.65	31.43	30.01	27.31
Imported	26.16	21.86	20.08	20.07	19.14

Note: Prices shown are quantity-weighted averages in year-of-delivery dollars (Energy Information Administration 1989c, p. 44, Table 35, and p. 50, Table 42)

Table D.3. Value of U_3O_8 Comprising the Generic Quad of Buildings Sector Energy

	U_3O_8 Value, millions of 1987 dollars	
Year	Domestic	Imported
1987	20	14
2010	19	14

Note: Both valuations are estimated with the 1987 price of U_3O_8 from Table D.2.

Spent Fuel Storage Valuation

This section develops an estimate of the cost of storing the radioactive spent fuel that is discharged during the "back end" of the nuclear fuel cycle. The assumptions of this analysis and the underlying cost estimates are from the *Final Version Dry Cask Storage Study (Dry Cask)* (Office of Civilian Radioactive Waste Management 1989).

Currently, spent fuel is stored under water in storage pools at reactor sites. These pools were designed to store a limited amount of spent fuel under the assumption that the fuel would be removed in a few years for chemical reprocessing. Ultimately, if there is insufficient storage-pool capacity, the utility must either remove some of the fuel from the water or cease operation. Two short-term solutions to this problem are to store some of the fuel from the pool in a dry mode, called dry cask storage, or to consolidate the fuel rods within the storage pool. The long-term solution, not yet available, is to store the spent fuel in an intermediate and/or permanent repository.

The central reference case examined *(Dry Cask)* assumes that there is no monitored retrievable storage facility for the intermediate storage of fuel, and that the geologic repository for long-term storage will not accept spent fuel before 2003. (At the current time, it does not appear that a permanent geologic repository will be built and ready to accept fuel until after 2010.) In addition, the report projects that even with the repository, the rate at which spent fuel will be discharged will exceed the rate at which it is removed from the reactor storage site until past the year 2010. As a consequence, at-reactor storage emerges as an important means of managing and storing the spent fuel for the intermediate term.

Five technologies considered in *Dry Cask* are in-pool rod consolidation, metal casks, concrete casks, horizontal concrete modules, and modular concrete vaults. In-pool rod consolidation has been demonstrated on a limited basis in the United States, although no production-scale campaigns have been conducted. The storage of fuel in metal casks is currently the most mature of the dry-storage technologies in the United States, and has been demonstrated since 1984. Concrete cask storage has not been implemented in the United States, but has been used extensively in Canada. One facility using horizontal concrete modules has been licensed in the United States, and others are in various stages of development. Modular concrete vaults have not been implemented in the United States, although they are extensively used in the United Kingdom.

Table D.4 provides the high- and low-cost estimates per kilogram of heavy metal storage for each option. The estimates show the expected average cost per kilogram for three different levels of increase in spent fuel storage capacity. The capacity increases are given in metric tons of heavy metal (MTHM). (One metric ton is equal to 1000 kg.) Economies of scale are evidenced for each of the options.

To value the spent fuel associated with the generic quad of buildings energy use, two assumptions are made. First, the metal cask technology is selected as the method of storage because 1) onsite pool storage capacity is very limited and 2) it is apparently commercially viable and has been demonstrated in a world price of oil, so it was assumed that a reduction in demand would be felt in the import sector. However, this is not the case for the United States. Second, the cost selected, $80/kg, is the simple average for the range for the 300-MTHM storage capacity level. This level is chosen because it is the mid-case. The estimated quantities of spent fuel for 1987 and 2010 are 36.3 and 28.7 MTHM, respectively, which provides a storage value of approximately $3 million in 1987 and 2.3 million in 2010.

These costs are a lower-bound estimate of total storage expenses because they reflect short-term

Table D.4. At-Reactor Unit Storage Costs for Spent Fuel for Five Storage Technologies

Storage Technology	Unit Storage Costs, $/kg heavy metal[a] by Storage Capacity Level 100 MTHM	300 MTHM	1000 MTHM
In-Pool Rod Consolidation	40-75	30-50	N/A[b]
Metal Casks	60-115	55-105	55-100
Concrete Casks	50-110	45-95	45-85
Horizontal Concrete Modules	60-80	45-60	40-55
Modular Concrete Vaults	105-155	70-105	45-70

(a) Costs show a low-high range, and are average costs.
(b) An increase of 1000 MTHM is not applicable to rod consolidation because at a typical reactor not much more than approximately 350 MTHM of additional storage space can be gained through consolidation.
Source: Office of Civilian Radioactive Waste Management (1989, p. I-86).

storage only and do not include long-term storage costs in geologic repositories, which are currently unknown.

Consumer Savings

Another way to view the economic value of the generic quad of energy is from the perspective of the final consumer--the owners and occupants of residential and commercial buildings who purchase the delivered energy. From economic theory, the consumer's perspective will capture all of the above valuations, because investment in new capacity and the purchase, conversion, transportation/transmission, and disposal of the fuels will be capitalized in the billing rate to the final consumer.

The one quad of generic source energy, as it is billed to the final consumer at the building site, is separated by the residential and commercial sectors to develop the consumer value, because the prices for the fuels in the two sectors are different. The fuel quantities associated with the generic quad and the prices by sector for 1987 and 2010 are shown in Table D.5 with the total consumer value of the energy. The electricity quantities are expressed in delivered energy to correspond to the price data used from *LREP* (p. 3-13, Table 3.3).

It should be noted that the prices in *LREP* are average, and not marginal, prices. To estimate the expenditures by consumers most accurately, economic theory indicates that marginal prices are preferable to average prices. *LREP* contains only the latter, however.

The prices for coal and renewable energy sources consumed on-site for the residential and commercial building sectors are not available in the *LREP* forecasts. These two fuels comprise less than 9% of the total projected site consumption for the generic quad in both years. Given this, the estimated annual consumer value of $5.5 billion and $7.6 billion for the generic quad for 1987 and 2010 is on the low side, yet is consistent with the other values derived in this appendix, as renewables were not included in the other estimations.

Table D.5. Consumer Value of One Generic Quad, 1987 and 2010

Year	Fuel	Total TBtu	Residential TBtu	Residential $1986/MBtu	Commercial TBtu	Commercial $1986/MBtu	Total Value, millions
1987	Petroleum	91	50.0	4.46	41.0	3.08	349
	Natural Gas	241	154.2	5.57	86.8	4.94	1288
	Electricity[(a)]	191	101.2	20.34	89.8	20.56	3905
						Total	**5542**
2010	Petroleum	56	24.1	12.39	31.9	10.03	619
	Natural Gas	194	114.5	11.28	79.5	10.80	2150
	Electricity[(a)]	207	114.3	23.52	92.7	23.41	4858
						Total	**7627**

(a) Electricity is expressed in TBtu of delivered energy; conversion to source Btu may be accomplished by dividing the 1987 quantity by 0.304 and the 2010 quantity by 0.292.

The consumer value for the three fuel types is also developed on a per TBtu basis as shown in Table D.6 using the information in Table D.5. The values in million dollars per TBtu are shown for residential and commercial sectors separately and for the two sectors combined on a weighted average basis.

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Table D.6. Consumer Value per TBtu of Petroleum, Natural Gas, and Primary Electricity, 1987 and 2010

	1987 Value, millions of 1986 Dollars		
	Residential	Commercial	Combined
Petroleum	4.46	3.08	3.84
Natural Gas	5.57	4.94	5.34
Electricity[(a)]	20.34	20.56	20.44

	1987 Value, millions of 1986 Dollars		
	Residential	Commercial	Combined
Petroleum	12.39	10.03	11.05
Natural Gas	11.28	10.80	11.08
Electricity[(a)]	23.52	23.41	23.47

(a) Electricity prices are expressed in million dollars per TBtu delivered energy; conversion to value per TBtu source energy may be accomplished by multiplying the 1987 value by 0.304 and the 2010 value by 0.292.

Appendix E

Residential and Commercial Fuel Share Tables

Appendix E

Residential and Commercial Fuel Share Tables

Table E.1. Direct Energy Consumption and Fuel Shares in the Residential Buildings Sector, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]					
Year	Coal	Natural Gas	Petroleum	Electricity	Dispersed Renewables	Total
1960	4.6	36.2	25.5	27.0	6.8	100
1965	2.4	37.9	23.4	31.7	4.7	100
1970	1.1	36.1	20.1	39.7	2.9	100
1975	0.6	33.8	16.8	46.1	2.7	100
1980	0.4	30.6	11.0	53.0	5.0	100
1985	0.4	28.1	9.5	55.9	6.2	100
1987	0.4	26.8	9.3	57.5	6.0	100
2000	0.5	24.9	6.2	62.6	5.7	100
2010	0.4	20.2	4.4	69.2	5.7	100

(a) Shares may not add to 100% because of rounding.

Table E.2. Residential Buildings Sector Indirect Fuel Shares, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	13.9	5.9	1.8	5.3	0.0	0.0	26.9
1965	16.7	6.9	2.1	5.8	0.1	0.0	31.6
1970	17.7	9.9	5.2	6.4	0.6	0.0	39.8
1975	19.9	7.3	7.2	7.2	4.3	0.2	46.1
1980	26.2	8.2	5.7	6.7	5.9	0.2	52.9
1985	30.7	6.7	2.3	7.0	8.7	0.4	55.8
1987	31.5	6.1	2.6	6.4	10.3	0.5	57.4
2000	36.8	4.4	2.3	6.3	10.9	1.9	62.6
2010	44.1	2.2	1.3	5.6	11.4	4.6	69.2

(a) Shares may not sum to total because of rounding.

Table E.3. Residential Buildings Sector Fuel Shares by Source Fuel Type, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	18.5	42.0	27.3	5.3	0.0	6.8	100
1965	19.1	44.8	25.4	5.8	0.1	4.7	100
1970	18.8	46.0	25.3	6.4	0.6	3.0	100
1975	20.5	41.1	24.0	7.2	4.3	2.9	100
1980	26.6	38.8	16.7	6.7	5.9	5.3	100
1985	31.2	34.7	11.8	7.0	8.7	6.6	100
1987	31.9	32.9	11.9	6.4	10.3	6.5	100
2000	37.3	29.3	8.5	6.2	10.9	7.7	100
2010	44.5	22.5	5.7	5.6	11.4	10.3	100

(a) Shares may not add to 100% because of rounding.

Table E.4. Direct Energy Consumption and Fuel Shares in the Commercial Buildings Sector, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]					
Year	Coal	Natural Gas	Petroleum	Electricity	Dispersed Renewables	Total
1960	12.0	22.2	25.8	39.9	0.0	100
1965	6.0	25.1	23.5	45.3	0.0	100
1970	2.6	29.4	18.6	49.4	0.0	100
1975	1.3	27.1	13.9	57.8	0.0	100
1980	0.8	25.2	12.2	61.8	0.0	100
1985	0.9	21.6	8.9	68.5	0.9	100
1987	0.8	20.4	8.9	69.9	0.8	100
2000	0.7	20.4	8.6	70.3	1.3	100
2010	0.6	18.2	7.4	73.9	2.3	100

(a) Shares may not add to 100% because of rounding.

Table E.5. Commercial Buildings Sector Indirect Fuel Shares by Source Fuel Type, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	20.6	8.7	2.7	7.9	0.0	0.0	39.9
1965	23.9	9.9	3.0	8.3	0.2	0.0	45.3
1970	21.9	12.3	6.4	0.8	0.7	0.0	49.3
1975	24.9	9.2	9.0	9.0	5.4	0.2	57.7
1980	30.6	9.6	6.6	7.8	6.9	0.3	61.8
1985	37.7	8.2	2.8	8.6	10.7	0.5	68.5
1987	38.3	7.4	3.2	7.7	12.5	0.6	69.7
2000	41.4	4.9	2.6	7.0	12.3	2.2	70.4
2010	47.1	2.4	1.3	6.0	12.1	4.9	73.8

(a) Shares may not sum to total because of rounding.

Table E.6. Commercial Buildings Sector Fuel Shares by Source Fuel Type, 1960 Through 1987, 2000, and 2010

	Shares, Percent[a]						
Year	Coal	Natural Gas	Petroleum	Hydro-Electric	Nuclear	Renewables	Total
1960	32.6	30.9	28.5	7.9	0.0	0.0	100
1965	30.0	35.0	26.5	8.3	0.2	0.0	100
1970	24.5	41.7	25.0	8.0	0.7	0.0	100
1975	26.3	36.2	22.9	9.0	5.4	0.2	100
1980	31.5	34.8	18.8	7.8	6.9	0.3	100
1985	38.6	29.8	11.8	8.6	10.7	1.4	100
1987	39.2	27.9	12.0	7.7	12.5	1.4	100
2000	42.0	25.4	11.1	7.0	12.2	3.5	100
2010	47.6	20.6	8.7	6.0	12.1	7.2	100

(a) Shares may not add to 100% because of rounding.

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