Appendix F

Alternatives for Estimating Energy Consumption

> **This appendix is reprinted from the *Annual Energy Review 2010*. EIA continues to review alternative options for accounting for energy consumption and related losses, such as those associated with the generation and distribution of electricity.**

I. Introduction

This year, the U.S. Energy Information Administration (EIA) has examined different ways to represent energy consumption in the *Annual Energy Review* (*AER*). This examination centered on two methods for representing related aspects of energy consumption and losses. The first is an alternative method for deriving the energy content of noncombustible renewable resources, which has been implemented in AER 2010 (Table 1.3). The second is a new representation of delivered total energy and energy losses.

This appendix provides an explanation of these alternative methods. Section II provides a background discussion of the alternatives and the reasons for considering these changes to the energy balance presentation. Section III identifies the specific changes incorporated in AER 2010.

II. Background

Alternative Approaches for Deriving Energy Contents for Noncombustible Renewables

EIA compiles data on most energy sources in physical units, such as barrels and cubic feet, in order to calculate total primary energy consumption. Before aggregation, EIA converts data for these energy sources to the common unit of British thermal units (Btu), a measure that is based on the thermal conversion of energy resources to heat and power.

Noncombustible renewables are resources from which energy is extracted without the burning or combustion of a fuel. They include hydroelectric, geothermal, solar, and wind energy. Because power from noncombustible renewables is produced without fuel combustion, there are no set Btu conversion factors for these energy sources.

In the past, EIA has represented hydroelectric, solar, and wind energy consumed for electric generation as the amount of energy it would require, on average, to produce an equivalent number of kilowatthours (kWh) of electricity using fossil fuels. In this appendix, this approach is referred to as the "fossil-fuel equivalency" approach. For the remaining noncombustible renewable resource, geothermal energy, energy consumed for electricity generation has been based on estimates of plant efficiencies in converting geothermal energy to electricity.

The fossil-fuel equivalency approach evolved in an era when the primary goal of U.S. energy policy was reducing dependence on imported petroleum and when a significant amount of electricity was generated using fuel oil. It was intended to indicate the amount of fossil energy displaced by the renewable energy source. But fuel oil is no longer used to generate electricity to a substantial degree and the international community largely uses a different approach, applying the constant conversion factor of 3,412 Btu/kWh. In addition, using a separate approach for geothermal generation may distort the analysis of the relative share of this generation resource. EIA also has a desire to better account for energy losses and efficiency. For these reasons, EIA considered three alternative methods for deriving the energy contents for noncombustible renewables, designated here as the fossil-fuel equivalency, captured energy, and incident energy approaches.

Fossil-Fuel Equivalency Approach

With this approach, EIA would continue to apply the fossil-fuel equivalent conversion factor to hydroelectric, solar, and wind energy and would begin applying it to geothermal energy. This approach would eliminate the inconsistency between geothermal and other noncombustibles, enable fuel displacement analysis, and

maintain the continuity of a data series with which users are familiar. However, the fossil-fuel equivalency approach does not represent any real market quantity. It measures neither primary energy consumed nor fossil fuel actually displaced. Additionally, its use will likely become increasingly problematic if renewables begin to displace other renewables instead of fossil fuels.

Captured Energy Approach

With this approach, EIA would apply the fixed factor of 3,412 Btu/kWh (the Btu value of electric energy generated) to measure the renewable energy consumed for electric generation for all noncombustible renewables. Using this approach would effectively count as primary energy only that noncombustible renewable energy that is captured for economic use.

EIA will use the term captured energy in referring to the energy actually "captured" by a noncombustible renewable energy system for final use. Thus, it is the net energy available for consumption after transformation of a noncombustible renewable resource into a usable energy carrier (such as electricity) or energy that is directly used. Another way of stating it is that captured energy is the energy measured as the "output" of the device, such as electricity from a wind turbine or solar plant.

This approach would not require EIA to make generalized assumptions regarding the actual conversion of these resources (wind, sunshine, falling water) into electricity. It would move U.S. reporting standards closer to international norms, which have been vetted by the International Energy Agency (IEA) and the international energy statistical community through years of actual use. Additionally, this approach better shows the economically significant energy transformations in the United States because the "lost" noncombustible renewable energy does not incur any significant economic cost (there is no market for the resource-specific energy apart from its immediate, site-specific energy conversion, and there is no substantive opportunity cost to its continued exploitation.[1]) On the other hand, this approach implies that conversion of noncombustible renewable energy is 100-percent efficient. In other words, it implies that there is no physical energy loss from the conversion of noncombustible renewables to electricity. In fact, renewable energy conversion can be very inefficient (largely because of the lack of alternative economic uses discussed above). Thus, this approach does not provide an accurate measure of the physical consumption of energy to produce electricity from these resources.

Incident Energy Approach

With this approach, EIA would use actual or estimated energy efficiencies of renewable conversion technologies to determine the Btu value of the input energy used to produce reported renewable generation. For example, rather than treating the electricity generated at a solar plant as primary energy, an empirical estimate of the actual portion of solar radiation incident on the solar panel that is converted to electricity would be used.

EIA will define "incident energy" for noncombustible renewable resources as the gross energy that first strikes an energy conversion device. In contrast to captured energy, incident energy is the mechanical, radiation, or thermal energy that is measurable at the "input" of the device. For wind, this would be the energy contained in the wind that passes through the rotor disc; for solar, the energy contained in the sunlight that strikes the panel or collector mirror; for hydroelectric, the energy contained in the water passing through the penstock (a closed conduit for carrying water to the turbines); and, for geothermal, the energy contained in the hot fluid at the surface of the wellbore.

This approach lends itself to a view of showing the physical reality of energy transformations in the United States. However, few renewable energy plants track cumulative input energy because of its lack of economic significance. Therefore, it would be difficult to obtain accurate estimates of efficiency without creating undue burden on survey respondents. Furthermore, this approach has not been vetted in the energy statistics community and its use would be inconsistent with IEA and other international statistics.

Table F1 shows factors that could be used to estimate the energy incident on the primary energy collection device of a noncombustible renewable power plant. These factors represent energy output as a percent of energy input. The conversion efficiency of renewable generation equipment is generally specified by the manufacturer, although this specification may differ from realized efficiencies for several reasons, including: the effects of balance-of-plant factors; environmental conditions that are different than conditions that the equipment was rated for; and variability in operating conditions for equipment that is rated under fixed conditions. The efficiencies shown in this table are not estimates of the actual, operational efficiency of the technologies indicated. Rather they are notional indications of the efficiencies that each technology may be able to achieve with typical equipment operating within the normal operating range for that technology.

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[1] There is an initial opportunity cost when first building such a facility: the water behind a dam might inundate land with alternative uses or a solar panel might shade some area that could otherwise use the sunlight. But that is a "fixed" opportunity cost that does not effectively change by normal operation of the plant.

Table F1. Conversion Efficiencies of Noncombustible Renewable Energy Sources

(Percent)

Source	Notional Efficiency[1]
Geothermal	16
Conventional Hydroelectric	90
Solar Photovoltaic	12
Solar Thermal Power	21
Wind	26

[1] Efficiencies may vary significantly for each technology based on site-specific technology and environmental factors. Factors shown represent engineering estimates for typical equipment under specific operational conditions.

Sources: **Geothermal:** Estimated by EIA on the basis of an informal survey of relevant plants. **Conventional Hydroelectric:** Based on published estimates for the efficiency of large-scale hydroelectric plants. See http://www.usbr.gov/power/edu/pamphlet.pdf. **Solar Photovoltaic:** Based on the average rated efficiency for a sample of commercially available modules. Rated efficiency is the conversion efficiency under standard test conditions, which represents a fixed, controlled operating point for the equipment; efficiency can vary with temperature and the strength of incident sunlight. Rated efficiencies are based on the direct current (DC) output of the module; since grid-tied applications require alternating current (AC) output, efficiencies are adjusted to account for a 20 percent reduction in output when converting from DC to AC. **Solar Thermal Power:** Estimated by dividing the rated maximum power available from the generator by the power available under standard solar conditions (1,000 W/m2) from the aperture area of solar collectors. **Wind:** Based on the average efficiency at rated wind speed for a sample of commercially available wind turbines. The rated wind speed is the minimum wind speed at which a turbine achieves its nameplate rated output under standard atmospheric conditions. Efficiency is calculated by dividing the nameplate rated power by the power available from the wind stream intercepted by the rotor disc at the rated wind speed.

Conclusion

After review of the three options, EIA has elected to follow a hybrid of the first two approaches for the AER 2010. The primary energy value of noncombustible renewables consumed for electricity generation will be measured using the fossil-fuel equivalent factor. However, this value will be reported as the sum of captured energy and an "Adjustment for Fossil Fuel Equivalence," which is the difference between the fossil-fuel equivalent value and the value obtained using the 3,412 Btu/kWh factor. This adjustment value represents the energy loss that would have been incurred if the electricity had been generated by fossil fuels. For solar and geothermal energy used directly, EIA will continue to use the factors currently employed.

This method will not cause a change to total primary energy consumption of hydro, solar, or wind energy, but it will allow users to easily distinguish actual economic energy consumption from the imputed displacement value, which is retained both to provide backward compatibility for data users accustomed to this measure and to allow for easier analysis of certain energy efficiency and production trends. The separate reporting of captured energy will also facilitate comparisons with international data sets.

For geothermal energy consumed to generate electricity, EIA will recalculate current and historical values using the fossil-fuel equivalent factor. This recalculation will change the following values presented in the AER 2010: the primary consumption of total energy (Tables 1.1 and 1.3); the consumption of geothermal for electricity generation (Tables 8.4a and b); and the consumption of renewable energy (Tables 10.1 and 10.2c).

New Representation of Delivered Total Energy and Energy Losses

The examination of heat rates for noncombustible fuels led EIA to also consider alternative methods of accounting for final energy consumption and energy losses. Final energy consumption differs from primary energy consumption in that it represents the amount (in terms of Btu) of energy actually consumed, in its final form, by an end user. For example, primary energy consumption of coal includes all the heat content in the coal consumed, while final energy consumption will include only the heat content of any coal consumed in its original form and the heat content of any products transformed from coal, such as electricity generated from coal.

EIA analyzed energy transformation in the United States. In all transformation processes, some useful energy is lost in achieving the conversion from one energy form to another. The most significant losses, by far, occur when electricity is generated from primary energy resources. Figure F1 illustrates an alternate method of accounting for energy consumption, based on the concept of delivered total energy.

In the AER 2010, as in previous AERs, the electric power sector is viewed as an energy-consuming sector. For each of the end-use sectors – residential, commercial, industrial, and transportation – total energy consumption is made up of the primary energy source consumed plus electricity retail sales and electrical system energy losses. Electrical system energy losses include transformation losses, the adjustment for fossil fuel equivalence (as discussed above), power plant use of electricity, transmission and distribution losses, and unaccounted for electricity. They are allocated to the end-use demand sectors in proportion to each sector's share of total electricity sales.

In the alternative representation (Figure F1), the electric power sector is not treated as an energy-consuming sector but as a sector that transforms and redistributes energy to final users. In order to better represent the amount of energy actually consumed by the final user, this method eliminates the allocation of electrical system energy losses to consuming sectors. Electricity retail sales to each sector, as reported by energy service providers, continue to be viewed as end-use consumption and, thus, are included in Delivered Total Energy. In Figure F1, delivered total energy represents the gross energy that enters an end-use facility (home, business, factory, and so forth). In some cases, there are conversion or transformation processes within the facility that create additional losses before the final consumption of the energy, so that the net energy consumed for useful application will be less than shown in the figure. For example, natural gas furnaces typically lose some amount of heat in the chimney, energy which then does not go toward heating the building.

Table F2 provides a comparison of Primary Energy Consumption and Delivered Total Energy by energy-use sector. Sources for Primary Energy Consumption by sector are AER Tables 5.14, 6.5, 7.3, 8.9, and 10.2. Data from those tables are converted from physical units to Btu using heat contents given in Appendix A. Sources for Delivered Total Energy are AER Tables 2.1 b through e.

III. Changes to the AER 2010

The major change to AER 2010 is the modification of Table 1.3 to incorporate the new treatment of noncombustible renewable energy consumption. The value of geothermal energy consumption and, consequently, total primary energy consumption is slightly lower than previously published for all years due to the use of a new geothermal conversion factor (the fossil-fuels heat rate from Table A6). See Section II of this appendix for further explanation.

The sum of hydroelectric, geothermal, solar, and wind primary consumption is now shown as total primary energy consumption for noncombustible renewables. That total includes: geothermal heat pump and direct use of geothermal energy; solar thermal direct use energy; and noncombustible resources that are transformed into electricity. Noncombustible resources transformed into electricity are equal to electricity generation from all noncombustible renewables converted to Btu using the fossil-fuels heat rate. Direct final consumption of geothermal and solar energy is obtained from AER Tables 10.2a and 10.2b.

Total primary consumption for noncombustible renewables is the sum of captured energy (or energy produced) and the "adjustment for fossil fuel equivalence." Like total primary consumption, captured energy includes: geothermal heat pump and direct use of geothermal energy; solar thermal direct use energy; and noncombustible resources that are transformed into electricity. However, electricity generation for all noncombustible renewables is converted to Btu using the energy content of electricity, 3,412 Btu per kWh.
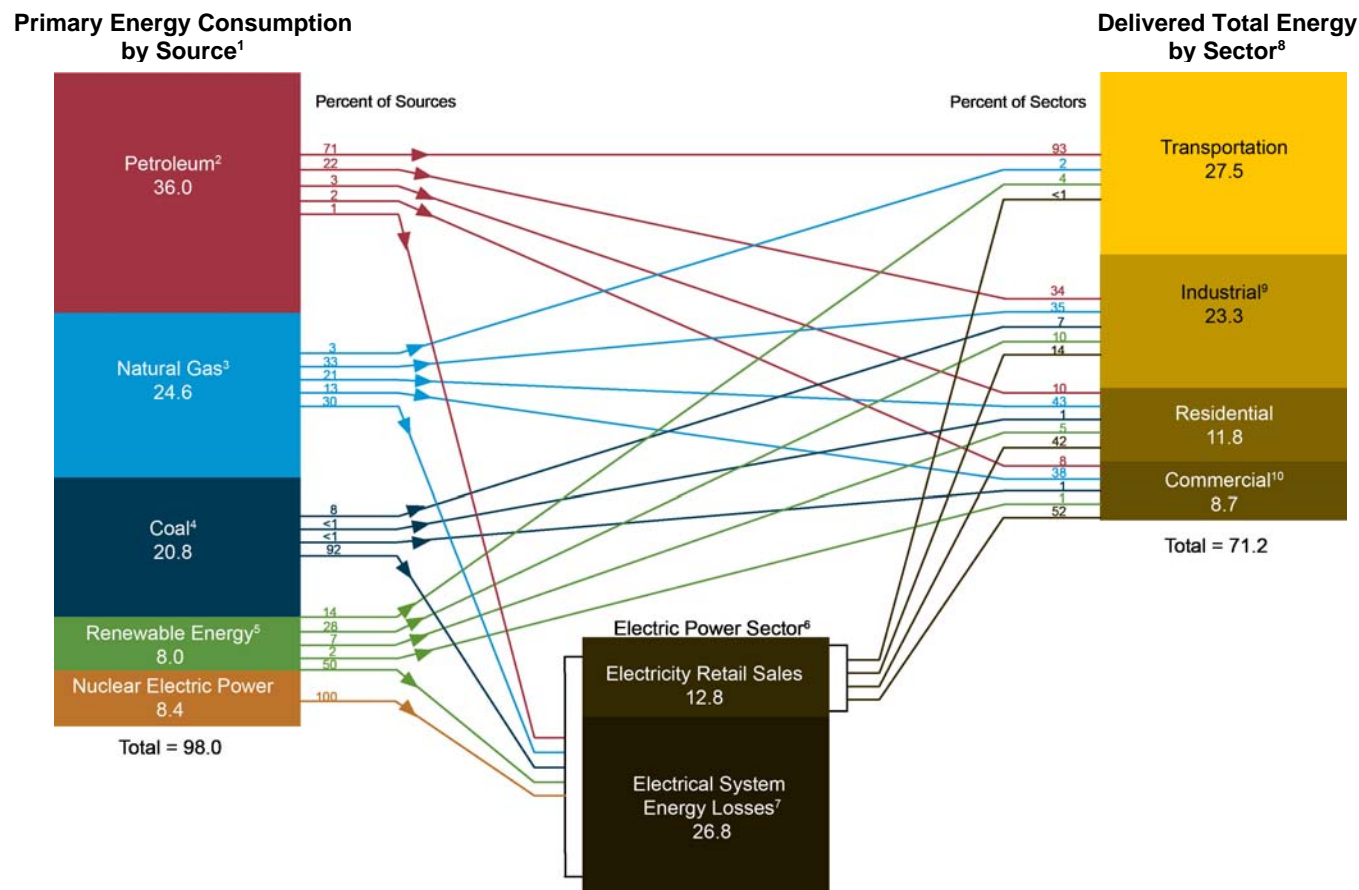
The "adjustment for fossil fuel equivalence" is equal to the difference between total primary consumption of noncombustibles in Btu (calculated using the fossil-fuels heat rate) and captured energy. There is no adjustment for fossil fuel equivalence associated with direct consumption of geothermal and solar energy.

In order to prevent any inconsistency between data presented in the modified Table 1.3 and the AER Section 10, "Renewable Energy," EIA will show data for the individual noncombustible renewables (hydroelectricity, wind, etc.,) in Section 10 only. In the AER 2010, total primary energy consumed for individual noncombustible renewables can be found in Table 10.1. A detailed breakout of the noncombustible renewable consumption components summarized in Table 1.3 is provided in Table F3. Table F3 shows the components of captured energy and the adjustment for fossil fuel equivalence (regarded as a loss), by individual energy source, for 2010. The columns labeled "Transformed into Electricity" represent the energy value of electricity generated from each type of noncombustible renewable resource. These values are calculated by multiplying net generation in Table 8.2 by 3,412 Btu/kWh.

For each noncombustible renewable, the adjustment for fossil fuel equivalence is calculated as the difference between the fossil fuel equivalent value of electricity generated and the value of "Transformed into Electricity." [2] For geothermal, direct consumption is the heat either captured and used directly from thermal ground water sources or extracted by ground-source heat pump. Values are from Tables 10.2a and 10.2b. Solar/PV direct consumption includes solar thermal energy used directly in the residential and electric power sectors. These values are from Tables 10.2a and 10.2c. Captured energy is equal to energy "transformed into electricity" for conventional hydroelectricity and wind. For geothermal and solar/PV, captured energy equals the sum of direct consumption and energy transformed into electricity.

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[2] The fossil fuel equivalent value of electricity generated is equal to electricity in kWh times the average heat content of the fossil fuel mix actually consumed in generating electricity for a given year.

Figure F1. Primary Energy Consumption and Delivered Total Energy, 2010

(Quadrillion Btu)

Primary Energy Consumption by Source[1]

Percent of Sources

Petroleum[2]
36.0

Natural Gas[3]
24.6

Coal[4]
20.8

Renewable Energy[5]
8.0

Nuclear Electric Power
8.4

Total = 98.0

Delivered Total Energy by Sector[8]

Percent of Sectors

Transportation
27.5

Industrial[9]
23.3

Residential
11.8

Commercial[10]
8.7

Total = 71.2

Electric Power Sector[6]

Electricity Retail Sales
12.8

Electrical System Energy Losses[7]
26.8

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[1] Includes electricity net imports, not shown separately.
[2] Does not include biofuels that have been blended with petroleum–biofuels are included in "Renewable Energy."
[3] Excludes supplemental gaseous fuels.
[4] Includes less than 0.1 quadrillion Btu of coal coke net exports.
[5] Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
[6] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.
[7] Calculated as the primary energy consumed by the electric power sector minus the energy content of electricity retail sales. See Note, "Electrical System Energy Losses," at end of Section 2.

[8] Includes transformation losses other than electrical system energy losses. For example, see notes 9 and 10 on this page.
[9] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[10] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
Note: Sum of components may not equal total due to independent rounding.
Sources: U.S. Energy Information Administration, *Annual Energy Review 2010*, Tables 1.3, 2.1b-f, 10.3, and 10.4.

Table F2. Energy Consumption by Sector, 2010
(Quadrillion Btu)

Year	Primary Energy Consumption[1]						Delivered Total Energy[2]					Electrical System Energy Losses[4]
	Residential	Commercial	Industrial[3]	Transportation[3]	Electric Power	Total	Residential	Commercial	Industrial	Transportation	Total	
2010	6,841	4,175	19,984	27,425	39,579	98,004	11,791	8,711	23,267	27,451	71,220	26,784

[1] Includes Adjustment for Fossil Fuel Equivalence. See "Primary Energy Consumption" in Glossary.
[2] Includes electricity sales to each sector in addition to Primary Energy consumed in the sector.
[3] Small amounts of coal consumed for transportation are reported as industrial sector consumption. Includes net imports of supplemental liquids and coal coke.
[4] Calculated as the primary energy consumed by the electric power sector minus the energy content of electricity retail sales.

Table F3. Noncombustible Renewable Primary Energy Consumption by Energy Source, 2010
(Trillion Btu)

Year	Noncombustible Renewables													
	Conventional Hydroelectric Power[1]			Geothermal[2]				Solar/PV[3]				Wind		
	Transformed into Electricity[4]	Adjustment for Fossil Fuel Equivalence[5]	Total Primary Energy[6]	Direct Consumption[7]	Transformed into Electricity[4]	Adjustment for Fossil Fuel Equivalence[5]	Total Primary Energy[8]	Direct Consumption[9]	Transformed into Electricity[4]	Adjustment for Fossil Fuel Equivalence[5]	Total Primary Energy[8]	Transformed into Electricity[4]	Adjustment for Fossil Fuel Equivalence[5]	Total Primary Energy[6]
2010	877	1,632	2,509	60	53	99	212	97	4	8	109	323	601	924

[1] Excludes pumped storage.
[2] Geothermal heat pump energy and geothermal heat used to generate electricity.
[3] Solar thermal and photovoltaic energy.
[4] Equals generation in kilowatthours (kWh) multiplied by the energy conversion factor of 3,412 Btu/kWh.
[5] Equal to the difference between the fossil fuel-equivalent value of electricity and the energy content of the final consumed electricity. The fossil fuel-equivalent value of electricity equals generation in kilowatthours multiplied by the average heat rate of fossil-fueled plants. The energy content of final consumed electricity equals generation in kilowatthours multiplied by the energy conversion factor of 3,412 Btu/KWh.
[6] Equal to generation in kilowatthours multiplied by the average heat rate of fossil-fueled plants.
[7] Reported Btu of geothermal heat pump and direct use energy.
[8] Includes direct consumption of resources and resources transformed to electricity. Resources transformed to electricity are equal to generation in kilowatthours (kWh) multiplied by the average heat rate of fossil-fueled plants.
[9] Residential sector direct use of solar thermal and photovoltaic (PV) electricity net generation (converted to Btu using the average heat rate of fossil-fueled plants).