ENERGY STAR Performance Ratings
Methodology for Incorporating Source Energy Use

The purpose of this document is to provide technical detail on the methodology undertaken by EPA to incorporate source energy into the national energy performance ratings. This document is structured as follows:

I. Overview

EPA's national energy performance ratings evaluate the performance of buildings that use all types of energy. To compare this diverse set of commercial buildings equitably, the ratings must express the consumption of each type of energy in a single common unit. EPA has determined that ***source energy*** is the most equitable unit of evaluation. Source energy represents the total amount of raw fuel that is required to operate the building. It incorporates all transmission, delivery, and production losses, thereby enabling a complete assessment of energy efficiency in a building.

Most building managers are familiar with ***site energy***, the amount of heat and electricity consumed by a building as reflected in utility bills. Site energy may be delivered to a facility in one of two forms: primary and/or secondary energy. ***Primary energy*** is the *raw fuel* that is burned to create heat and electricity, such as natural gas or fuel oil used in onsite generation. ***Secondary energy*** is the energy product (heat or electricity) created from a raw fuel, such as electricity purchased from the grid or heat received from a district steam system. A unit of primary and a unit of secondary energy consumed at the site are not directly comparable because one represents a raw fuel while the other represents a converted fuel. Therefore, in order to assess the relative efficiencies of buildings with varying proportions of primary and secondary energy consumption, it is necessary to convert these two types of energy into equivalent units of raw fuel consumed to generate that one unit of energy consumed on-site. To achieve this equivalency, EPA uses the convention of source energy.

When primary energy is consumed on site, the conversion to source energy must account for losses that are incurred in the storage, transport and delivery of fuel to the building. When secondary energy is consumed on site, the conversion must account for losses incurred in the production, transmission, and delivery to the site. The factors used to restate primary and secondary energy in terms of the total equivalent source energy units are called the ***source-site ratios***. EPA uses national average ratios to accomplish the conversion to source energy because ENERGY STAR is a national program and because the use of national average source-site ratios ensures that no specific building will be credited (or penalized) for the relative efficiency of its energy provider(s).

Whether heat and electricity used at a building come from fuel burned on or off-site, there is always a potential for inefficiency in the conversion of primary fuels, and there is also a potential for loss when either primary or secondary fuels are transmitted/distributed to individual sites. These inefficiencies represent energy that was embodied in an original primary fuel, but that was not ultimately used at the building: potential heat, work, or electricity was sacrificed. If the losses were reduced, the building could operate with less overall fuel consumption, produce lower CO_2 emissions, and cost less to operate. The EPA comparison of buildings using source energy accounts for these losses, providing a complete energy assessment of the building. In addition, source energy comparisons generally reflect energy costs and carbon emissions more accurately than site energy.

Source-site energy ratios are applied to convert each kBtu of energy used on site into the total kBtu of equivalent source energy consumed. **Table 1**, following, summarizes the source-site ratios for each fuel in Portfolio Manager. Specific calculations and reference documents for each fuel are presented in Section IV.

Table 1 Source-Site Ratios for all Portfolio Manager Fuels	
Fuel Type	**Source-Site Ratio**
Electricity (Grid Purchase)	3.34
Electricity (on-Site Solar or Wind Installation)	1.0
Natural Gas	1.047
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.01
Propane & Liquid Propane	1.01
Steam	1.21
Hot Water	1.28
Chilled Water	1.05
Wood	1.0
Coal/Coke	1.0
Other	1.0

II. The Value of Source Energy

The purpose of the conversion from site energy to source energy is to provide an equitable assessment of building-level energy efficiency. Because billed site energy use includes a combination of primary and secondary forms of energy, a comparison using site energy does not provide an equivalent thermodynamic assessment for buildings with different fuel mixes. In contrast, source energy incorporates all transmission, delivery, and production losses, which accounts for all primary fuel consumption and enables a complete assessment of energy efficiency in a building.

When source energy is used to evaluate energy performance, an individual building's performance does not receive either a credit or a penalty for using any particular fuel type. In contrast, use of a site energy metric would provide a credit for buildings that purchase energy produced off site by a utility (such as electricity). The following discussion and analysis demonstrate this neutrality. For example, one quarter of the buildings that earned the ENERGY STAR in 2006 operate using 100% electricity. This is equivalent to the percent of buildings in the national population that use 100% electricity. Moreover, the building comparison presented in **Table 3** shows that source energy will correctly recognize efficient heating systems independent of fuel choice. Therefore, because EPA adopts source energy as the primary unit of comparison, using a particular fuel does not in itself make a building more or less likely to earn the ENERGY STAR.

Energy Consumption in ENERGY STAR Buildings

Source energy conversions are needed to account for the fact that buildings use different mixes of fuels, and primary and secondary energy cannot be compared directly. When the conversions are applied correctly, a building is no more or less likely to earn the ENERGY STAR based on the type of fuel consumed. **Table 2** compares the types of fuels used by the office buildings that earned the ENERGY STAR in 2006 with the office buildings in the Commercial Building Energy Consumption Survey (CBECS). CBECS is a nationally representative quadrennial survey completed by the Department of Energy's Energy Information Administration. EPA uses the data in this survey to develop the energy performance ratings.

Table 2
Comparison of Fuel Use
ENERGY STAR Office Buildings and National Commercial Office Building Population

	CBECS 2003 Data Set	ENERGY STAR Class of 2006
Number of Buildings	498	332
Average Percent Electricity Used	68%	85%
Average Percent Natural Gas/Other Fuel Used	32%	15%
Percent of Buildings Using 100% Electricity	25%	25%

Note

- *CBECS 2003 – The Commercial Building Energy Consumption Survey. This is a national survey conducted every four years by the Energy Information Administration. Complete information on the survey, including public data files, is available at: http://www.eia.doe.gov/emeu/cbecs/contents.html. The average values presented are weighted using the survey sampling weights and are computed using Office buildings only, applying the standard set of filters used to create the ENERGY STAR performance rating model. Information on these filters is available in the document: Technical Methodology for Office, Bank/Financial Institution, and Courthouse (http://www.energystar.gov/ia/business/evaluate_performance/office_tech_desc.pdf).*
- *ENERGY STAR – These values are averages, weighted by floor space, and computed across those office buildings which earned the ENERGY STAR during the year 2006.*

On average, ENERGY STAR office buildings have a fuel mix that is approximately 85% electricity. This is a higher average percent of electricity than the national commercial building population, which on average uses 68% electricity. The higher percent of electric use among ENERGY STAR offices may reflect the fact that offices that have applied for the ENERGY STAR are more likely to be large buildings with high plug loads. Generally, the fuel profile of ENERGY STAR buildings is similar to the fuel profile of the national population, with electricity accounting for the majority of on-site fuel consumption. Moreover, the percent of ENERGY STAR office buildings that use only electricity (25%) is equivalent to the percent of office buildings in the country that use only electricity. Hence, on a national basis an all-electric building is no more (or less) likely to earn the ENERGY STAR.

Source Energy in Different Heating Scenarios

Because most buildings use electricity for lighting and other equipment, the reason that fuel mix varies by building is usually due to the choice of heating system. Another way to understand the relationship between fuel choice, source energy, and energy performance is to consider six different scenarios for heating systems in buildings. For each scenario, assume that the building has the same operation and the same thermal envelope. Therefore, the heat load for each building is identical. The differences among the buildings are solely in the type of fuel and the equipment used for heating. The six scenarios are as follows:

- **Building A** is heated using natural gas. The boiler has a combustion efficiency of 90%. With standby and distribution losses, the overall system efficiency is 80%. This is considered a highly efficient natural gas system.

- **Building B** is heated using natural gas. The boiler has a combustion efficiency of 70%. With standby and distribution losses, the overall system efficiency is 55%. This is considered a relatively inefficient natural gas system, which might be found in an older building with poor maintenance, unsophisticated controls, and limited insulation.
- **Building C** is heated using district steam. Minor losses occur onsite due to steam distribution, resulting in an on-site system efficiency of 95%. This is a highly efficient steam system.
- **Building D** is heated with electricity using a geothermal system, incorporating heat pumps with a coefficient of performance (COP) of 4.0. This is considered a highly efficient system.
- **Building E** is heated with electricity using an air source heat pump system, incorporating heat pumps with a COP of 2.5. This is considered an efficient heat pump system.
- **Building F** is heated using electric resistance heating. While minor line losses can occur with resistance heating, electric resistance converts nearly 100% of the electricity received from the utility into heat. However, due to the large amount of primary fuel required to generate the electricity for resistance heating, it is considered to be the least efficient form of electric heat based on a complete thermodynamic assessment.

If the buildings are identical (i.e. have the same construction, thermal envelope, and operation), and each has the same heating load of 1000 MBtu, then the site and source energy consumption can be expressed as shown in **Table 3**. These site and source energy values demonstrate the key differences and illustrate why source energy is the more equitable comparative metric.

Table 3
Comparison of Alternate Heating Scenarios

	Building A	**Building B**	**Building C**	**Building D**	**Building E**	**Building F**
Heating System	NG Boiler, 80% system efficiency	NG Boiler, 55% system efficiency	District Steam, 95% system efficiency	Geothermal COP=4.0	Air Source Heat Pump, COP=2.5	Electric Resistance Heat
Heating Fuel	**Natural Gas**	**Natural Gas**	**District Steam**	**Electric**	**Electric**	**Electric**
Heat delivered to Space (MBtu)	1000	1000	1000	1000	1000	1000
Site Energy (MBtu)	1250	1818	1053	250	400	1000
Source Energy (MBtu)	1309	1903	1274	835	1336	3340

Note that the following source-site ratios were applied:
- *Electricity: 1 unit site = 3.34 units source*
- *Natural Gas: 1 unit site = 1.047 units source*
- *Steam: 1 unit site = 1.21 units source*

A comparison of these building scenarios using site energy fails to recognize highly efficient systems and improperly rewards inefficient systems, as described below:

- A site energy comparison suggests that all types of electric heating systems are more efficient than natural gas and steam systems. While geothermal systems (Building D) and air source heat pumps (Building E) can be more efficient or comparable to natural gas and steam, the electric resistance heating system (Building E) requires far more primary fuel in its operation. From a thermodynamic perspective, this building would be falsely rewarded using a site energy system.

- A site energy evaluation suggests that the district steam system will be significantly more efficient than any on-site natural gas boiler system. While a steam system can offer great efficiencies by enabling a utility to run a higher more consistent load, there are still losses associated with the production and distribution of steam to the site that are not accounted for in a site energy evaluation. A conventional district steam utility delivers heat to the building with an efficiency of 83% (see Section IV). When these loses are incorporated, the steam system is shown to be more comparable to the efficient natural gas system (Building A).

In contrast, source energy provides an accurate and equitable comparison of these building scenarios, as described below:

- A source energy comparison correctly classifies the geothermal heat pump (Building D) as the most efficient technology. At the same time, source energy provides a more equitable comparison of this efficient technology with the most efficient natural gas technologies (Building A).

- Source energy captures the inefficiencies inherent in the generation and distribution of electricity. Therefore, a source energy comparison shows that electric resistance heating provides the worst energy performance. Source energy also incorporates on-site inefficiencies, which is why the less efficient on-site natural gas system (Building B) has the second worst energy performance.

The EPA energy performance ratings are developed to express the complete energy efficiency of a building. In this context the preceding heating scenarios illustrate that source energy provides a more accurate and equitable assessment than site energy.

III. Methodology

Ultimately, the goal of the conversion to source energy is to account for the total primary fuel needed to deliver heat and electricity to the site. Generally this means the methodology should perform the following adjustments for energy consumed on site:

- **Primary Energy** (e.g. natural gas, fuel oil) – Account for losses that occur in the distribution, storage and dispensing of the primary fuel.
- **Secondary Energy** (e.g. electricity, district steam) – Account for conversion losses at the plant in addition to losses incurred during transmission and distribution of secondary energy to the building.

Specific details on the application of this methodology to each type of energy are provided in Section IV.

These adjustments quantify the total energy content of the primary fuel. In this assessment, the primary fuels are considered refined products such as coal, natural gas and oil. The analysis does not account for the energy that is consumed in mining, transporting, and refining crude products. While this type of analysis may provide an instructive look at the lifecycle costs of energy use, it is beyond the scope of a building-level assessment.

Use of National Average Source-Site Ratios

The efficiency of secondary energy (e.g. electricity) production depends on the types of primary fuels that are consumed and the specific equipment that is used. These characteristics are unique to specific power plants and differ across regions of the country. For example, some states have a higher percentage of hydroelectric power, while others consume greater quantities of coal. Because ENERGY STAR is a national program for energy efficiency, EPA has determined that it is most equitable to employ national-level source-site ratios. As such, there is only one source-site ratio for each of the primary and secondary fuels in Portfolio Manager, including grid purchases of electricity.

There are a few reasons why national source-site ratios provide the most equitable approach:

1) The geographic location is fixed for most buildings; there is no opportunity to relocate the building to a region with more efficient electrical production.
2) For most buildings it is not possible to trace each kWh of electricity back to a specific power plant. Across a given utility region, the grid is connected and the electric consumption of a specific building cannot be associated with any individual plant.
3) The key unit of analysis for Portfolio Manager is the building. It is the efficiency of the building, not the utility, which is evaluated. Two buildings with identical operation and energy efficiency will receive the same rating regardless of their geographic location or utility company[1].

The use of national source-site ratios ensures that no specific building will be credited (or penalized) for the relative efficiency of its utility provider.

On-Site Fuel Conversion

The objective of the conversion to source energy is to quantify the total amount of energy, by accounting for conversion, transmission, and distribution losses. When energy conversion occurs on site, the losses (or gains) from this conversion are accounted for in site energy because the building is assessed based on the fuel that is purchased. Conversion of fuel on site can take a variety of forms. At a simple level this could include combustion of natural gas in a boiler to generate heat. A more complex system may be a Combined Heat and Power (CHP) system, which converts natural gas into both heat and electricity. In the case of either a CHP system or a natural gas boiler, the required input for Portfolio Manager is the natural gas fuel purchase. The

[1] Note that two buildings with equivalent energy *efficiency* in two different regions may have different *absolute energy consumption* owing to weather conditions. The ENERGY STAR rating accounts for climate differences in this situation, providing an equitable comparison for buildings in different climates. The use of source energy ensures that a building does not receive either a credit or a penalty based on its utility provider.

efficiency of the energy conversion (by the boiler or CHP system) is reflected in the quantity of natural gas purchased, and the source conversion factor for natural gas accounts for only the transmission and distribution losses.

If the boiler or CHP system produces heat and/or electricity more efficiently than these products can be produced by the utility, then the conversion loss on site is not as great as the conversion loss associated with purchasing those products from a utility. In this case, the building with the efficient CHP system or boiler would use less total energy than a building purchasing equivalent heat and electricity from a utility; hence, the building with the efficient CHP system or boiler will earn a better rating. Sometimes the reverse can be true, and the on-site production will be less efficient. A building with production that is less efficient than the average utility will not rate as well as a building purchasing those products from the utility. The efficacy of any specific equipment at a building will depend on proper installation, operation, and maintenance.

Treatment of Renewable Energy

Off-site renewable energy generation:
The electric grid in the United States includes a variety of renewable sources of electricity, including wind power, solar power, and hydroelectric power. These renewable sources of energy do not depend on the consumption of any fossil fuels; rather there is conversion of energy directly from sun, wind, or water. Although renewable energy is not subject to the same conversion losses as other fuels, an individual building or facility is typically not able to trace each kWh of electricity to a specific power generation plant. Therefore, a building may be located in a utility region that includes multiple forms of electric generation including wind, hydroelectric, and coal but because the grid is interconnected, it is not possible to assign a specific production method to a specific building. Moreover, as noted above, individual buildings do not have control over the available power supply options in their geographic area. Therefore, EPA uses national source-site ratios, which reflect the proportion of renewable electric generation on the national grid.

The energy performance rating is focused on energy consumption, not the resulting emissions or energy supplier. The application of a single national electric factor ensures that no particular building is credited or penalized based on its utility provider. By focusing on the *building* rather than the energy supply, the rating can help a building owner or manager optimize his or her energy efficiency. Efficiency is the first step to achieving a zero carbon building. Once a building is as energy efficient as possible, the purchase of green power, through either utility green pricing products, or Renewable Energy Certificates (RECs) is an option for reducing indirect greenhouse gas emissions and reducing the overall carbon footprint. Portfolio Manager enables tracking of these green power purchases and the corresponding avoided emissions. It is recommended that these purchases be tracked alongside the building energy efficiency (i.e. rating), to motivate superior, high performance buildings. Note that the purchase of green power does not make the building itself any more or less efficient in its energy consumption. Hence, green power does not impact the source energy or rating calculations.

On-site renewable energy generation:
When renewable energy is produced at a building through solar photovoltaic panels or wind turbines, the goal of the source energy factor is sill to account for conversion, transmission, and distribution loses. In this case, there is not an analogous conversion loss because electricity is derived from the sun or the wind, which are not considered discrete organic fuels, such as fossil fuels. In addition, because the electricity is converted on-site, there is no transmission or distribution. Hence, the source-site ratio for on-site solar or wind electricity is 1.0. Because on-site solar and wind do not have the losses that are incurred when electricity is purchased from the grid, the application of these on-site technologies will be associated with lower source energy and higher energy performance ratings.

Wood is also considered a form of on-site renewable energy, which is purchased and burned on-site. Wood is a primary form of energy; when it is combusted on site there is a conversion loss. In this case, the source conversion factor should account for transmission and distribution loses. There are not considered to be any transmission or distribution losses associated with the delivery of wood to a site. Therefore, the source-site ratio for wood is 1.0.

Other types of on-site renewable energy may include purchase and combustion of landfill gas or biomass fuels. At this time, Portfolio Manager does not offer fuel choice options for these forms of energy and therefore cannot rate buildings that use them. In the interest of providing the best assessment of energy and carbon, EPA plans to expand on-site renewable reporting options in the future. An assessment of what types of energy must be included and how to incorporate this energy is underway.

Timeframe for Updating Source-Site Ratios

The most recent revision of all source-site ratios occurred in 2007; since that time EPA has added factors to account for energy use from on-site renewable systems and to account for the prevalence of CHP systems in the production of district steam. The source-site ratios computed and applied in the Portfolio Manager tool depend on several characteristics, including the quality of the fuels, the average efficiency of conversion from primary to secondary energy, and the distribution efficiency. Therefore, over time the ratios are expected to change as the national infrastructure and fuel mix evolve. Characteristics that impact the ratios do not change drastically from one year to the next, but may be expected to change over time. Therefore, EPA reviews the ratios every 3 to 5 years, and updates accordingly.

IV. Source-Site Ratios by Energy Type

This section presents the specific reference documents and calculations used to derive the source-site ratios for each type of energy available in Portfolio Manager.

Electricity

When electricity is consumed at a site it must be designated as a grid purchase, or as an on-site solar or wind product. The conversion factors are as follows.

Grid Purchased Electricity

When electricity is purchased from a utility, it is a secondary form of energy that is consumed at a building. Grid electricity is generated through a variety of methods including the burning of fossil fuels (e.g. coal, natural gas, fuel oil), from nuclear plants, and from renewable sources including wind, hydropower, and biomass. The source-site ratio for electricity must reflect the losses that are incurred when these fuels are converted from their primary form into electricity, and also for any losses that occur on the electric grid as the electricity is transported to specific buildings.

These values can be computed directly from the Electricity Flow Diagram, included in the Energy Information Administration's Annual Energy Review[2]. As shown in the diagram, the mix of electric production in the United States is approximately 70% fossil fuel, 20% nuclear, and 10% renewable (hydropower, biomass, solar, wind, geothermal). The source-site ratio is calculated as Primary Energy (i.e. the total primary energy involved in electricity generation) divided by Net Generation less Transmission and Distribution (T&D) Losses. This calculation is summarized in **Table 4**. As shown, the source-site ratio can be calculated separately for any given year, and varies slightly over time. Because a building in Portfolio Manager can have multiple years of data and different buildings have energy data for different time periods, EPA has computed an average over five years to apply as the standard conversion in the development of rating models and the rating of individual buildings. The source-site ratio for grid electricity is 3.340.

Table 4
Source-Site Ratio Calculations for Electricity

Year	Primary Energy Consumed for Generation	Net Generation	T&D Losses	Source-Site Ratio
2001	38.56	12.69	1.20	3.356
2002	39.56	13.10	1.24	3.336
2003	39.62	13.13	1.24	3.332
2004	40.77	13.49	1.28	3.339
2005	41.60	13.78	1.31	3.336
Average (2001-2005)				**3.340**

Source:
Electricity Flow (Figure 8.0) in the Annual Energy Review. Values in Quadrillion Btus (Quads). *http://www.eia.doe.gov/emeu/aer/contents.html*

On-Site Solar or Wind Electricity

When renewable energy is produced at a building through solar photovoltaic panels or wind turbines, the goal of the source energy factor is still to account for conversion, transmission, and distribution loses. In the case of on-site solar or wind energy there is not an analogous conversion loss because electricity is derived from the sun or the wind, which are not considered discrete organic fuels, such as fossil fuels. In addition, because the electricity is converted on-

[2] Every year, the Energy Information Administration publishes the Annual Energy Review at: http://www.eia.doe.gov/emeu/aer/contents.html. This web page also provides links to reports for previous years. Each report contains and Electric Flow Diagram: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec8_3.pdf

site, there is no transmission or distribution. Hence, the source-site ratio for on-site solar or wind electricity is 1.0.

Natural Gas

Natural gas is a type of primary energy that is burned on-site to produce heat and/or electricity. Because natural gas is a type of primary energy, the source-site ratio must account for losses incurred in pipeline transmission and distribution of natural gas from the provider to the customer. These values are obtained from the Natural Gas Annual, a regular publication of the Energy Information Administration. The source-site ratio can be computed directly from the information in Table 1 of the Natural Gas Annual, Summary Statistics for Natural Gas in the United States, 2001-2005[3].

The source-site ratio is obtained first by computing the sum of the delivery to consumers, the pipeline and distribution use, and the plant use, and then dividing this sum by the total delivery to consumers. This calculation indicates the total amount of gas that is used at the distribution plant or lost in transmission, for each unit of gas that is delivered to a consumer. As shown in **Table 5**, the source-site ratio for natural gas can be calculated separately for any given year, and varies slightly over time. Because a building in Portfolio Manager can have multiple years of data and different buildings have energy data for different time periods, EPA has computed an average over five years to apply as the standard conversion in the development of rating models and the rating of individual buildings. The source-site ratio for natural gas is 1.047.

Table 5
Source-Site Ratio Calculations for Natural Gas

Year	Sum of Pipeline and Distribution Use, Plant Fuel, and Delivery to Consumers (MM ft^3)	Sum of Pipeline and Distribution Use, Plant Fuel (MM ft^3)	Delivery to Consumers (MM ft^3)	Source-Site Ratio
2001	21,491,213	996,105	20,495,108	1.049
2002	22,276,435	1,049,423	21,227,012	1.049
2003	21,518,122	955,395	20,562,727	1.046
2004	21,657,411	932,528	20,724,883	1.045
2005	21,484,879	939,972	20,544,907	1.046
Average (2001-2005)				**1.047**

Source:
Table 1. Summary Statistics for Natural Gas in the United States, 2004-2005. *Natural Gas Annual 2005*. Excludes Lease Fuel to be consistent with the method for electricity.
http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html

[3] Every year the Energy Information Administration publishes the Natural Gas Annual at: http://www.eia.doe.gov/oil_gas/natural_gas/data_publications/natural_gas_annual/nga.html. This web page also provides links to reports for previous years. Each report contains a Table, *Summary Statistics for Natural Gas in the United States*
http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/current/pdf/table_001.pdf

Fuel Oil

Refined petroleum products are considered primary energy; they are burned on-site to produce heat and/or electricity. These products include fuel oil (# 1, 2, 4, 5, 6), diesel, and kerosene. As with other primary fuels, the source-site ratio for fuel oil must account for the losses occurred in fuel distribution, storage, and dispensing.

EIA does not produce an annual report that quantifies the losses associated with fuel oil distribution, storage and dispensing. However, several other detailed reports were reviewed to explore the lifecycle energy requirements for producing transportation fuels. The most suitable report for the desired estimate was determined to be A Lifecycle Emissions Study (LEM) conducted at the University of California, Davis[4]. From this study, estimates relating to the production and distribution of highway diesel fuel were determined to be the most analogous to the types of heating fuels found in commercial buildings[5]. The LEM study identifies the energy required for distribution and storage, and fuel dispensing, and the relative proportion of this energy use to the total end use. These figures are presented in **Table 6**. The proportion of diesel fuel that is used in distribution and storage and fuel dispensing is approximately 1% of the total delivery to customers. Therefore, the source-site ratio for fuel oil is 1.01.

Table 6
Summary of LEM Study Figures for Highway Diesel Fuel

Highway Diesel Fuel Lifecycle	Energy Required (Btu/mile)	Energy Proportion Relative to End Use
Fuel Distribution and Storage	189	0.8%
Fuel Dispensing	45	0.2%
End Use	24,600	100.0%
Total	**24,834**	**101.0%**

Source:
Table 51B, LEM Study, p. 400. Excludes feedstock recovery, transmission, and refining to be consistent with the method used for electricity.

Propane

Propane is a fuel that can be generated either as a bi-product of petroleum-refining or natural gas processing. Once created, propane is considered a primary fuel that is burned on site to produce heat and/or electricity. Because propane is a primary fuel, the source-site ratio must account for losses occurred in fuel distribution, storage, and dispensing. EIA does not produce an annual report that quantifies the losses associated with propane distribution, storage and dispensing. For propane, these losses are considered to be most analogous to those of fuel oil. Therefore, the source-site ratio for propane is 1.01.

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[4] A Lifecycle Emissions Model (LEM): Lifecycle Emissions from Transportation Fuels, Motor Vehicles, Transportation Modes, Electricity Use, Heating and Cooking Fuels, and Materials, Mark DeLucchi, Institution of Transportation Studies, University of California, Davis, December 2003. Found at: http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1064&context=itsdavis (LEM Study).

[5] Highway diesel fuel is a more refined product than fuel oil that may be used in buildings. However, the primary contributors to the source-site ratio (energy for distribution, storage, and dispensing of the fuel) are expected to be similar.

District Systems

District energy is secondary energy that is generated off-site and delivered to a facility in the form of steam, hot water, or chilled water. For secondary sources of energy, the source-site ratio must account for the losses that occur when the primary fuel is converted into the secondary form of energy (the production efficiency) and any losses that occur when the secondary energy is distributed to the facility (the distribution efficiency). Properties of these district systems, including ranges for the production and distribution efficiencies are referenced in a report titled *District Energy Services: Commercial Data Analysis for EIA's National Energy Modeling System.* This report was compiled for the Energy Information Administration by Energy and Environmental Analysis, Inc. (EEA) and the International District Energy Association (IDEA)[6]. The specific calculations for each of type of district energy system are discussed below.

District Steam

District steam is generated using conventional boiler technology and combined heat[7] and power (CHP) technology. The efficiency of conventional steam generation is dictated by the boiler. Typical boiler efficiencies range from 80% to 85% at full load (i.e. design) conditions. However, at partial load the efficiency will be lower, on the range of 90% to 97% of the design efficiency. Because one of the operating benefits of district heating systems is the ability to consolidate a number of varying load profiles into a single, more constant demand profile, it is reasonable to assume that district heating boilers will operate at relatively high annual load factors. Given this, the steam production efficiency can be evaluated at the midpoint of the boiler efficiency range and at the high end of the partial load efficiency range:

$$\text{(Boiler Efficiency)} * \text{(Partial Load Efficiency)} = (82.5\% * 97\ \%) = 80\%$$

Once steam is generated, some of the heat will be lost in transit between the production facility and the site of use. This distribution heat loss ranges from approximately 6% to 9%. The midpoint of this range (7.5%) can be used to evaluate the overall system efficiency:

$$\text{Production Efficiency} - \text{Distribution Loss} = 80\% - (7.5\% * 80\%) = 74\%$$

Therefore conventional steam production delivers heat to the site with a thermal efficiency of approximately 74%. Because only 74% of the thermal content of the original fuel is delivered to the building in the form of heat, it takes 1.35 kBtu of source energy to provide 1 kBtu of energy to the building. Hence, the source-site ratio for conventional district steam is 1.35.

District steam may also be produced using CHP technology. CHP systems are growing in market share and now comprise about 41.35% of the district steam market.[8] Therefore, CHP

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[6] Energy and Environmental Analysis, Inc. and International District Energy Association. *District Energy Services: Commercial Data Analysis for EIA's National Energy Modeling System.* Submitted to: Decision Analysis Corporation and Energy Information Administration. August 2007.

[7] In this case, synonymous with steam.

[8] EPA and its contractor ICF International derived the CHP market share estimates based on analysis of total steam delivery for the 50 identified downtown district steam systems. This analysis was an extension and update of the 2007 district steam assessment completed for the Department of Energy's Energy Information Administration. This assessment was completed by the Energy and Environmental Analysis Inc and the International District Energy Association.

system efficiency must be incorporated in the district steam source-site ratio to accurately reflect the steam market in its entirety. To determine a source-site ratio for steam produced through CHP district systems, data on the efficiency of these systems was examined.[9]

For a CHP district system, on average, the input energy, output energy and the resulting efficiency are:

- 100 units energy in → 34.5 units Steam + 28.1 units Electricity
- Conversion efficiency of 63%

If two traditional systems were used to produce the same amount of steam and electricity as the CHP system, the total input energy requirement would be greater than that of the CHP system. Assuming an 82.5% conversion efficiency for traditional steam and 32% conversion efficiency for traditional electricity, 41.8 units of input energy would be needed to produce the same amount of steam as the CHP system and 87.8 units of input energy would be needed to produce the same amount of electricity.[10] Therefore, the input energy, output energy and resulting efficiency using two traditional systems would be:

- 129.6 units energy in → 34.5 units Steam + 28.1 units Electricity
- Conversion efficiency of 48%

To determine the source-site factor for steam produced from CHP district systems, the primary energy used to generate the steam must be compared with the final delivery of steam to the facility. To compute the primary energy, it is necessary to divide the input energy of 100 units between both the electric and the steam products. To do this equitably, the percent can be based on the percent breakdown of input fuels in the reference traditional system case. This approach results in a fair division of the savings from CHP systems to each product. Of the 129.6 units of input energy for the traditional system, 41.8 units (32.26%) go toward steam production. Therefore, of the 100 units of input energy for the CHP district system, 32.26 units are considered to be the input energy used to generate steam.

The effective production efficiency of steam in a CHP district system can be then expressed as:

- Production Efficiency = 34.5 units output / 32.26 units input = 106.9%

The value over 100% occurs because of the combined efficiencies generated with CHP systems. As with traditional systems, it is also necessary to account for losses from the delivery of steam to the facility. The same 7.5% distribution loss can be applied:

Production Efficiency – Distribution Loss = 106.9% - (7.5% * 106.9%) = 98.9%

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[9] EPA estimated the percent CHP efficiency over traditional systems using estimates of CHP energy requirements and output derived from an updated 2007 ICF/IDEA assessment.

[10] To arrive at the input energy requirements the following steps were used:

- Input energy=Output energy/efficiency
- Steam input energy =34.5 units/0.825= 41.8 units
- Electricity input energy=28.1 units/.32= 87.8 units

CHP steam production delivers heat to a facility with a thermal efficiency of approximately 98.9%. Given this efficiency, it takes 1.01 kBtu of source energy to provide 1 kBtu of energy to the building. Hence, the source-site ratio for CHP district steam is 1.01.

The lower source-site ratio reflects the efficiency gains associated with using CHP as compared to traditional heat and power systems. To determine the overall district steam source-site factor, incorporating both CHP and non-CHP steam source-site factors is necessary. Therefore, a weighted average of the two source-site factors was taken:

(Conventional Steam Factor)*(% Conventional Steam) + (CHP Steam Factor)*(% CHP Steam)
= 1.35*(58.65%) + 1.01* (41.35%) =1.21.

Therefore, the national source-site ratio for district steam is 1.21.

District Hot Water

The efficiency of hot water generation is also dictated by the boiler and distribution losses. As with steam generation, boilers are designed to operate with an efficiency of 80% to 85%, and operational efficiencies are expected to be lower due to partial load operation. Thus the production efficiency for hot water is expected to be the same as steam, 80%.

For hot water, distribution losses are smaller than they are for steam, because hot water distribution is not subject to condensate loss. As such, the distribution losses associated with hot water range from 2% to 3%. Using the midpoint of this range (2.5%), the overall system efficiency can be computed:

Production Efficiency – Distribution Loss = 80% - (2.5% * 80%) = 78%

Therefore hot water production delivers heat to the site with a thermal efficiency of approximately 78%. Because only 78% of the thermal content of the original fuel is delivered to the building in the form of heat, it takes 1.28 kBtu of source energy to provide 1 kBtu of energy to the building. Hence, the source-site ratio for district hot water is 1.28.

District Chilled Water

Chilled water generation is characterized by two main technologies: electric chillers and gas fired chillers. Electric chillers make up the majority of chilled water generation, but each technology is discussed below.

The efficiency of electric chillers is described in terms of kW of electricity required per ton of cooling. In other words, the number of units of output cooling to input power is known as the Coefficient of Performance (COP) and ranges from 2.9 to 4.4. This range of output cooling (2.9 to 4.4 kW) is generated from each kW of input power[11]. Electric chillers will also be subject to a loss of up to 10% due to partial load operation. As such, the COP range is better stated as 2.6 to 4.0, which expresses the net production efficiency. The source-site ratio must also account for

[11] This range is based on an assumption of 0.8 to 1.2 kW per ton of cooling, with 1 ton of cooling equaling 12,000Btu/hr or 3.517 kW.

the distribution losses, which range from 2% to 3%. Subtracting this percent from the COP values, yields a range of 2.5 to 3.9. The midpoint of this range is 3.3; for each kBtu of energy required by the electric chiller, approximately 3.3 kBtu of energy is delivered to the building. This net COP can be restated:

1 kBtu cooling at the building = 0.3125 kBtu of electricity required at chiller

However, it is important to recall that the Btu requirement to drive the chiller is electric, and electricity is a secondary form of energy. Therefore, in order to quantify the total energy requirement, the energy requirement of the chiller must itself be multiplied by the source-site ratio for electricity (which is 3.34):

1 kBtu on-site cooling = 1.04 kBtu source energy

Thus for electric chillers (which constitute the majority), the source-site ratio is 1.04.

Natural gas fired chillers constitute a much smaller portion of total chilled water generation. These chillers are typically characterized by COP values of 0.7 to 1.4, indicating that 0.7 to 1.4 Btu of energy is provided for every Btu of natural gas that is consumed. As with electric chillers, actual operation is typically at partial load, which will reduce the production COP to 0.6 to 1.3. As with electric chillers, the distribution losses are estimated to be 2% to 3%. Subtracting these losses from the COP values yields a range of 0.6 to 1.2; the middle of this net range is 0.9, indicating that for each Btu of gas required by the chiller, 0.9 Btu are delivered to the building. This net COP can be restated:

1 kBtu cooling at the building = 1.11 kBtu of natural gas required at chiller

Because natural gas is a form of primary energy, an additional source-site calculation is not required. This primary energy consumption occurs at the power plant and therefore is not subject to the same distribution losses as at a commercial building.

Although the exact technology breakdown between natural gas and electric chillers is not well documented by either EIA or IDEA, electric chillers are known to be the dominant technology. The electric chilled water source-site ratio is 1.04, while the natural gas chilled water source-site ratio is 1.11. Assuming as much as 10 to 20% of chilled water comes from natural gas; the average ratio across the two technologies is 1.05. Therefore, the source-site ratio for district chilled water is 1.05.

Wood

Wood is also considered a form of on-site renewable energy, which is purchased and burned on-site. Wood is a primary form of energy; when it is combusted on site there is a conversion loss. In this case, the source conversion factor should account for transmission and distribution loses. There are not considered to be any transmission or distribution losses associated with the delivery of wood to a site. Therefore, the source-site ratio for wood is 1.0.

Coal

Coal is a fossil fuel that can be combusted at an individual facility to create heat and/or electricity. Because coal is a primary fuel, the source-site ratio must account for any losses that occur in the storage, transportation and delivery of coal to a building. There is no direct quantifiable loss of coal that occurs when it is stored, transported, or delivered to a facility. Therefore, the source-site ratio for coal is 1.0.

Other

In Portfolio Manager, EPA has built capacity for many types of fuels, each of which falls into one of the preceding categories. However, in the event that a building using a different fuel on-site (e.g., waste biomass), then a user may select the "Other" category. In these situations, because the primary fuel source is not reported, EPA cannot quantify any losses that are associated with conversion, transportation, or distribution. Hence, the source-site ratio is 1.0