NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Basics

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Presentation Overview

Energy vs. Power
Common Units
Forms of Energy
“Work” vs “Heat”
Three Laws of Thermodynamics
Electricity
U.S. Energy Flows
    Sources of Energy
    Energy Sectors

Energy & Power

ENERGY

Definition: the ability to do work

Equation: ENERGY = FORCE * DISTANCE

Energy is a quantity

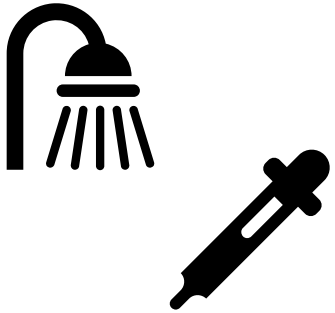
POWER

Definition: Rate at which energy is being created, moved, or used

Equation: POWER = ENERGY / TIME

Power is a rate (energy/time)

Energy equipment items (e.g. generators, boilers, switches) are usually rated in terms of their peak power. (E.g. 100 kW generator, 5 hp motor).



Units

1

ENERGY (Energy = Power x Time)

SI: Joule [J] (1 kg * m^2 / s^2)

1 MJ = 1,000,000 J

3

SI (Electrical): watt-hour [Wh] (= 3,600 joules)

1 kWh = 1,000 Wh = 3,600,000 joules

English (Heat): British Thermal Unit [BTU] (1 kWh = 3,412 BTU)

1 BTU is the amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit

2

POWER (Power = Energy / Time)

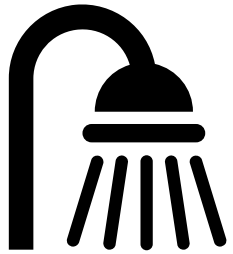
SI: watt (1 watt = 1 joule/second)

1 kW = 1,000 watts

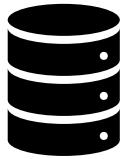
English (Heat): BTU/hour

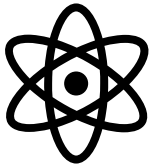
(1 kW = 3,412 BTU/hour)

English (mechanical): horsepower [hp] (1 hp = 0.7457 kW)

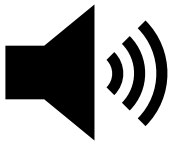


Forms of Energy





Potential energy	Kinetic energy
Potential energy is stored energy and the energy of position.	Kinetic energy is the motion of waves, electrons, atoms, molecules, substances, and objects.
Chemical energy is energy stored in the bonds of atoms and molecules. Batteries, biomass, petroleum, natural gas, and coal are examples of chemical energy. Chemical energy is converted to thermal energy when people burn wood in a fireplace or burn gasoline in a car's engine. **Mechanical energy** is energy stored in objects by tension. Compressed springs and stretched rubber bands are examples of stored mechanical energy. **Nuclear energy** is energy stored in the nucleus of an atom—the energy that holds the nucleus together. Large amounts of energy can be released when the nuclei are combined or split apart. **Gravitational energy** is energy stored in an object's height. The higher and heavier the object, the more gravitational energy is stored. When a person rides a bicycle down a steep hill and picks up speed, the gravitational energy is converting to motion energy. Hydropower is another example of gravitational energy, where gravity forces water down through a hydroelectric turbine to produce electricity.	**Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Sunshine is radiant energy, which provides the fuel and warmth that make life on earth possible. **Thermal energy**, or heat, is the energy that comes from the movement of atoms and molecules in a substance. Heat increases when these particles move faster. Geothermal energy is the thermal energy in the earth. **Motion energy** is energy stored in the movement of objects. The faster they move, the more energy is stored. It takes energy to get an object moving, and energy is released when an object slows down. Wind is an example of motion energy. A dramatic example of motion energy is a car crash —a car comes to a total stop and releases all of its motion energy at once in an uncontrolled instant. **Sound** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate. The energy is transferred through the substance in a wave. Typically, the energy in sound is smaller than in other forms of energy. **Electrical energy** is delivered by tiny charged particles called electrons, typically moving through a wire. Lightning is an example of electrical energy in nature.



EIA, https://www.eia.gov/kids/energy.php?page=about_forms_of_energy-basics , accessed 22 April 2019

Work vs. Heat

Work and heat are both forms of energy

"Work" can be thought of as "organized energy". (Examples: mechanical motion [e.g. a spinning wheel, a moving shaft], electricity)

"Heat" can be thought of as "disorganized energy"

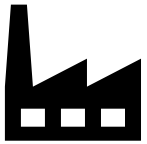
Q: Why do we care?

A: There is a big efficiency hit in going from heat to work. Typically 2/3 – 4/5 of the energy is lost in going from heat to work. Going from work to heat or from one form of work to another typically involves much less loss

Factoids to help with Intuition

Power consumption of a typical hairdryer: 1,000 – 1,500 watts (1.0 – 1.5 kW)

Average typical U.S. single family house electrical load: ~1 kW



Average monthly consumption of a typical U.S. house: 0.6 – 1.0 MWh (600 – 1,000 kWh)

Output of a large power plant: ~1,000 MW (1 million kW)

Total U.S. energy consumption in 2017: 97 quadrillion (97,000,000,000,000,000) BTUs. (28 trillion kWh) (97 quads) (1 quad = 1 quadrillion BTUs)

Factoids to help with Intuition

Fuel /Source	Energy
Coal[1]	24 – 35 MJ/kg (6 – 10 kWh_{TH}/kg)
Natural Gas[1]	54 MJ/kg (15 kWh_{TH}/kg)
Diesel fuel[1]	46 MJ/kg (13 kWh_{TH}/kg)
Wood (dry)[1]	18 MJ/kg (5 kWh_{TH}/kg)
Average solar global horizontal insolation within continental U.S.	3 – 6 kWh/m^2/day
Range of wind power density values	< 20 – 600+ $watts/m^2$

Note: 1 kg = 2.2 lbs

1. Wikipedia, https://en.wikipedia.org/wiki/Energy_density , accessed 22 April 2019

Other Terms, & Conversion Factors

1 year = 8,760 hours

1 (30 day) month = 720 hours

1 hour = 3,600 seconds

$$\text{Capacity Factor (CF)} = \frac{\text{Actual energy production over some time frame}}{\text{Possible energy production if the facility had produced at rated power over the whole of that time frame}}$$

Laws of Thermodynamics (for non-techies)

1. You can't get more energy out than you put in (You can't win)

2. Every time energy is converted from one form to another, there are losses (You can't break even)

3. (You can't quit the game)

Electricity

Item	Definition	SI Unit	SI Definition
Charge [Q}	Note 1 (charge is a quantity)	coulomb (C)	Note 2
Current [I]	Charge/time (analogous to flow rate in a pipe)	Ampere (A)	coulomb/second
Voltage [V]	Energy/unit charge (analogous to pressure in a pipe)	Volt (v)	Joule/coulomb

Note 1: Charge - "physical property of matter that causes it to experience a force when placed in an electromagnetic field"[1]

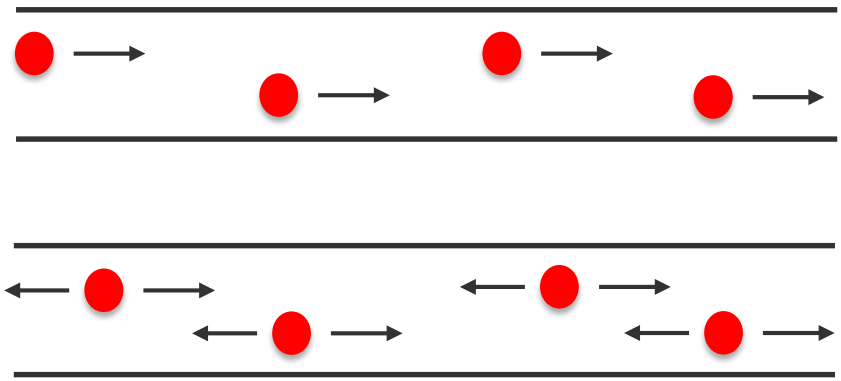
Note 2: 1 coulomb is the absolute magnitude of the charge in 6.241×10^{15} electrons or protons.[2]

Note that the power in an electric current is given by the current[I] times the voltage [V].

I x V : (coulombs / second) x (joules / coulomb) : joule / second

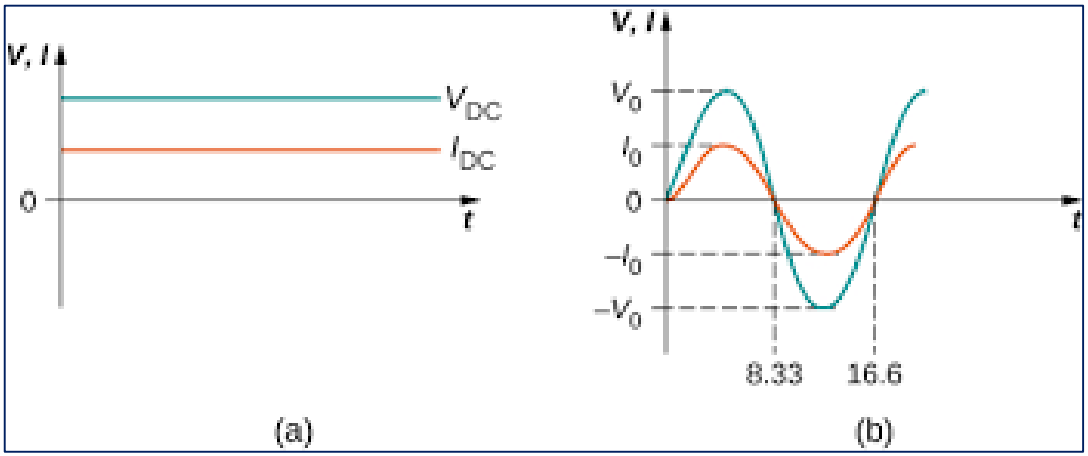
1. Wikipedia, https://en.wikipedia.org/wiki/Electric_charge , accessed 22 April 2019
2. Wikipedia, https://en.wikipedia.org/wiki/Coulomb , accessed 22 April 2019

Electricity – AC vs. DC



Direct Current

Alternating Current

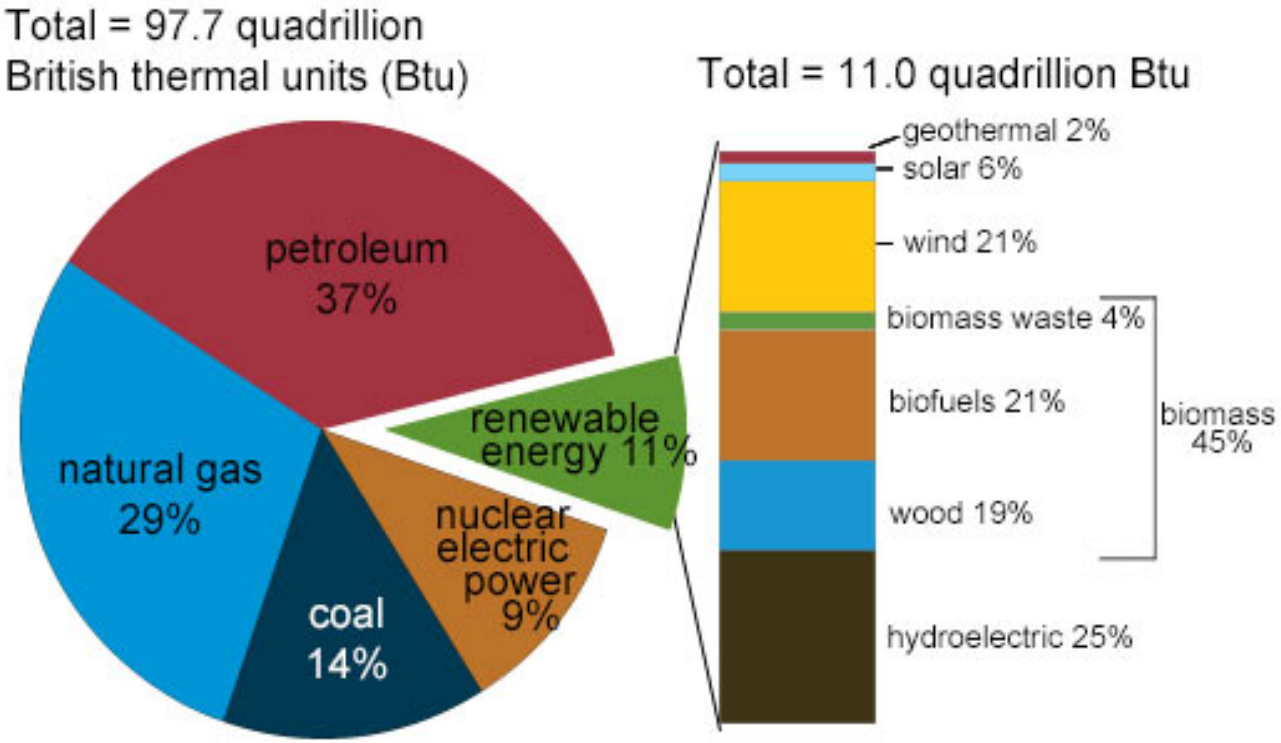


Direct Current Alternating Current

OpenStaxCollege, https://opentextbc.ca/physicstestbook2/chapter/alternating-current-versus-direct-current/ , Accessed 22 April 2019

Energy Sources

U.S. energy consumption by energy source, 2017



Note: Sum of components may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2018, preliminary data

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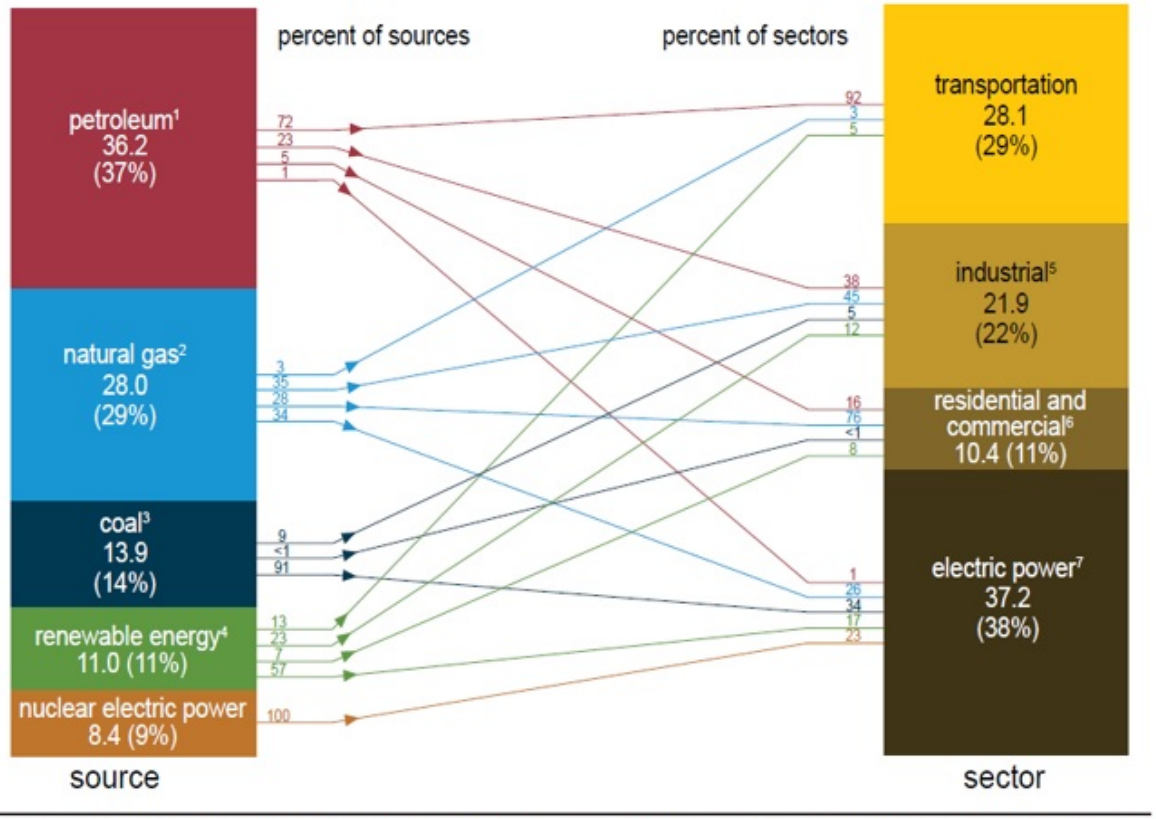
Energy Sources & Energy Sectors

U.S. primary energy consumption by source and sector, 2017

Total = 97.7 quadrillion British thermal units (Btu)



[1] Does not include biofuels that have been blended with petroleum—biofuels are included in "Renewable Energy."
[2] Excludes supplemental gaseous fuels.
[3] Includes -0.03 quadrillion Btu of coal coke net imports.
[4] Conventional hydroelectric power, geothermal, solar, wind, and biomass.
[5] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[6] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[7] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes 0.17 quadrillion Btu of electricity net imports not shown under "source."

Notes: • Primary energy is energy in the form that it is accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy occurs (for example, coal is used to generate electricity). • The source total may not equal the sector total because of differences in the heat contents of total, end-use, and electric power sector consumption of natural gas. • Data are preliminary. • Values are derived from source data prior to rounding. • Sum of components may not equal total due to independent rounding.

Sources: U.S. Energy Information Administration, *Monthly Energy Review* (April 2018), Tables 1.3, 1.4a, 1.4b, and 2.1-2.6.

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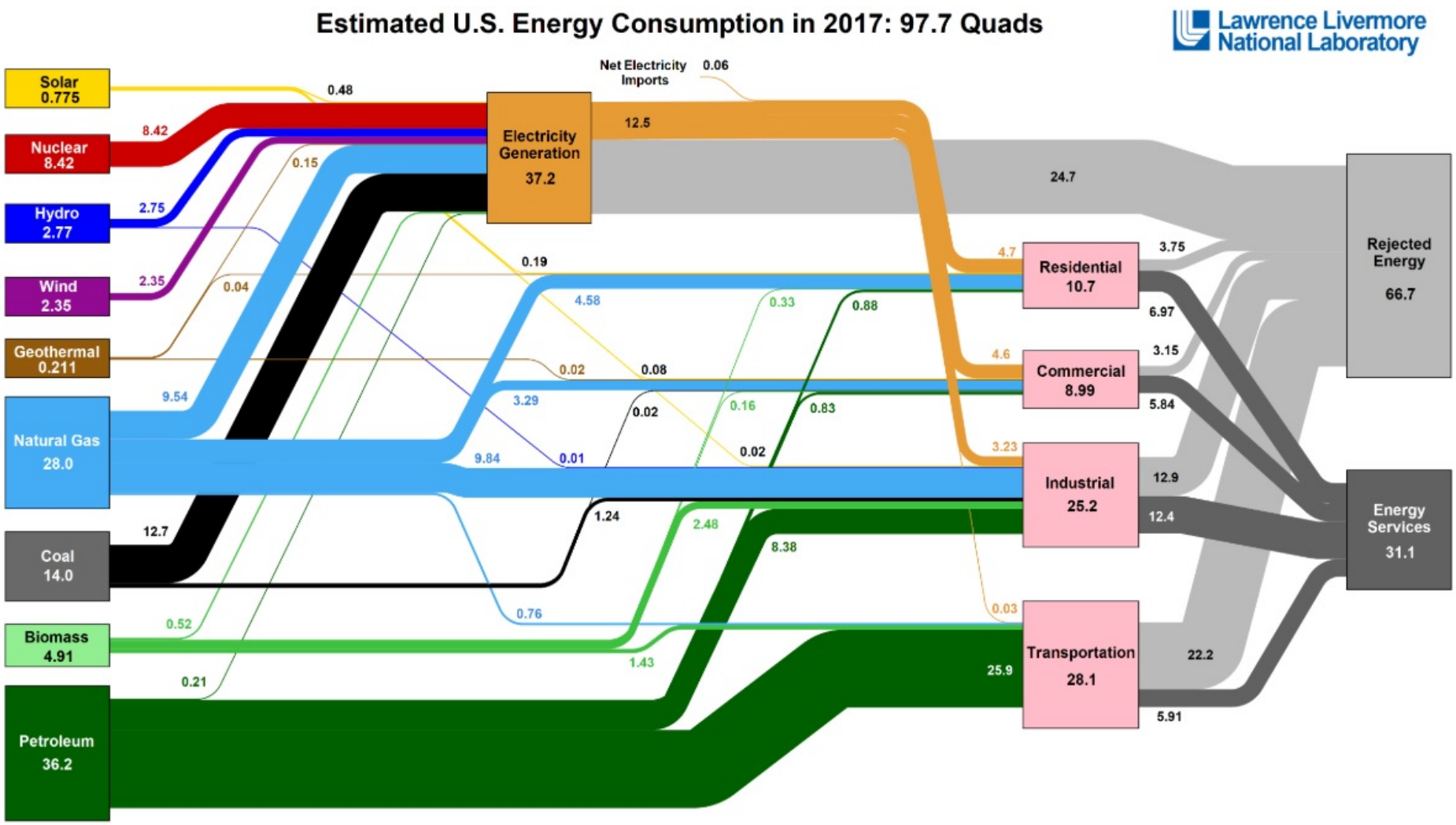
Energy Sources & Energy Sectors



Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

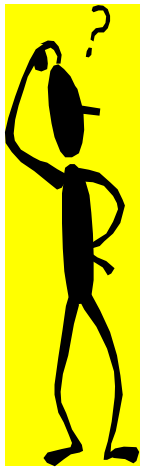
Resources & links

EIA, Energy Facts Explained, https://www.eia.gov/energyexplained/index.php

EIA, Energy Facts Explained-U.S. Energy Facts, https://www.eia.gov/energyexplained/?page=us_energy_home

LLNL, U.S. Energy Flow Charts, https://flowcharts.llnl.gov/commodities/energy

Questions?



Thank You

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