REET 3020

Energy Conversion

0 – Introduction

Energy

<u>Energy</u> can be defined as:

“the ability or capacity to do work”

or

“the property of a system that diminishes when the system does work on any other system, by an amount equal to the work so done.”

But, what exactly does this mean?

https://www.dictionary.com/browse/energy

Energy

"Those of you with a bit of formal education were probably given a lesson on energy at some point in your life. If so, then the chances are pretty good that you were given a definition of energy as "the ability to do work". If you were a good student or you just wanted to please your teacher, you probably heard this and said to yourself, "OK, energy is the ability to do work." If you were a really good student with a desire to learn or a really bad student with a desire to point out your teacher's intellectual shortcomings, you should have then asked the next logical question. What is work?"

"Hopefully you were given the right answer, but chances are fifty-fifty you were shrugged off. Not because the right answer is so difficult to know, but rather because the right answer is so difficult to explain, or at least difficult to explain in a way that can be grasped quickly."

https://physics.info/work/

Energy

There are many different forms of energy:

- Mechanical
- Thermal
- Radiant (Electromagnetic)
- Geothermal
- Gravitational
- Electrical
- Chemical
- Nuclear
- Tidal
- Motion

All of these can forms of energy can fundamentally be sorted into two different types:

Kinetic Energy and Potential Energy

https://www.eia.gov/

Kinetic vs. Potential Energy

Kinetic energy is often referred to as "motional" energy, while potential energy is often referred to as "stored" energy (that can be used to create kinetic energy).

Although this concept may be useful when trying to gain a fundamental understanding of the concept of energy, it should be noted that energy can be "stored" in the form of kinetic energy.

For example, a flywheel is a heavy disk that is attached to a rotating shaft such that the energy associated with its rotation (momentum) can be utilized instantaneously to help maintain a uniform rotational speed despite transients in the mechanical loading of the system.

https://physics.info/energy/

Kinetic Energy

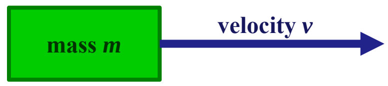
Kinetic Energy is energy associated with motion:

- Radiant Energy — electromagnetic waves
  - solar energy, light waves, x-rays, gamma rays, and radio waves
- Motional Energy — energy stored in the movement of objects
  - rotating machines, wind, waves (water, sound, etc.)
- Thermal Energy (Heat) — energy associated with the movement of atoms and molecules in a substance
  - geothermal energy
- Electric Energy — energy associated with the movement of charge
  - electricity (electric current), lightning

https://www.eia.gov/

Kinetic Energy

In <u>classic mechanics</u>, the kinetic energy of an object is the energy that it possesses due to its motion.



For example, kinetic energy of a non-rotating object of mass *m* traveling at speed *v* is:

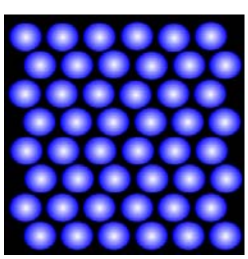
$$KE = \tfrac{1}{2} m v^2$$

The concept can also be extended to rotating objects in terms of the object's angular velocity and moment of inertia.

Kinetic Energy

Although it is easy to understand the concept of kinetic energy with respect to the motion of a solid body, other forms of kinetic energy can be abstract and hard to perceive.

For example, <u>thermal energy</u> is associated with the random motion of particles (molecules and atoms) at an atomic scale.



For example, as humans we may perceive no motion from a solid object at rest.

Yet, despite being held in place by the molecular structure of the material, the molecules may be vibrating or moving at an atomic scale.

This movement is associated with kinetic energy and is often characterized in terms of temperature.

Potential Energy

<u>Potential Energy</u> is energy associated with position (in a force field):

- **Gravitational Energy — energy stored in an object's height**
  - **– hydroelectric energy, rollercoasters, etc.**
- **Chemical Energy — energy stored in the bonds of atoms/molecules**
  - **– batteries, biomass, petroleum, natural gas, and coal**
- **Mechanical Energy — energy stored in objects by tension**
  - **– springs, rubber bands**
- **Nuclear Energy — energy stored in the nuclei of atoms that is released when the nuclei are combined or split**
  - **– the Sun's core (fusion), nuclear reactors & nuclear bombs (fission)**

https://www.eia.gov/

Work

<u>Work</u> can be defined as a measure of the amount of energy that is transferred from a system to its surroundings, or a measure of the amount of energy transformed from one form to another.

For example, the gasoline engine in a car:

The engine utilizes a spark to ignite a compressed gasoline/air mixture within a cylinder, triggering a chemical reaction that quickly releases a lot of energy in the form of expanding hot gasses (CO_2 and H_2O).
(chemical ➡ heat)

The pressure created by the superheated gasses drives a piston, the linear motion of which is converted into rotational motion by a crankshaft, which will then be used to rotate the car's wheels propel the car.
(heat ➡ mechanical)

Units of Energy or Work

Since work is a measure of an amount of energy, both work and energy will have the same units.

Because of this, energy is often characterized by the amount of work performed by a system.

Standard units for energy include:

- **kWh (kilowatt·hours)**
- **BTUs (British Thermal Units)**
- **boe (barrel of oil equivalent)**
- **eV (electron-volts)**
- **joules**
- **calories**
- **quads**
- **therms**

Units of Energy or Work

A joule is equal to the amount of energy transferred to an object when a force of one newton acts on that object in the direction of motion through a distance of one meter.
(I.e. – 1 newton·meter or N·m)

A newton is the force required to accelerate a one kilogram mass at the rate of one meter/second^2 in the direction of the applied force.

A joule is also equal to the amount of energy dissipated as heat when an electric current of one ampere passes through a resistance of one ohm for one second.

Units of Energy and Work

A calorie is equal to the amount of energy (heat) required to raise the temperature of 1 gram (mL) of water by 1° Celsius (from 14.5°C→15.5°C at a pressure of 1 standard atmosphere).

(Note that the value will change with temperature)

1 calorie ≈ 4.2 joules

A BTU (British thermal unit) is equal to the amount of energy (heat) required to raise the temperature of one pound of water by 1° Fahrenheit.

1 BTU ≈ 1055 joules

Power

Power is the rate at which work is being performed or the amount of energy being transferred per unit time.

The standard unit of power is a watt, which is defined as a rate of energy transfer equal to one joule per second.

$$1\,\text{W} = 1\,\frac{\text{joule}}{\text{sec}}$$

A watt is also equal to the rate at which electrical work is performed when a current of one ampere (A) flows across an electrical potential difference of one volt (V).

$$1\,\text{W} = 1\,\text{V} \cdot 1\,\text{A}$$

The Cost of Energy

Another common unit of energy is a <u>kilowatt·hour</u> (kWh).

$$1\,\text{kWh} = 1{,}000\ \text{W} \cdot 1\,\text{hr} = 1{,}000\ \tfrac{\text{joules}}{\text{sec}} \cdot 1\,\text{hr} \cdot 60\ \tfrac{\text{min}}{\text{hr}} \cdot 60\ \tfrac{\text{sec}}{\text{min}} = 3{,}600{,}000\ \text{J}$$

Note that, on average, a US customer pays ~ \$0.10 per kWh of electricity.

This equates to:

$36\text{x}10^6$ joules/dollar

The average cost of electricity in 2017:
- **All Sectors ——— \$0.105 per kWh**
- **Commercial ——— \$0.107 per kWh**
- **Industrial ——— \$0.069 per kWh**
- **Residential (US) – \$0.129 per kWh**
- **Residential (GA) – \$0.126 per kWh**
- **Residential (NY) – \$0.188 per kWh**
- **Residential (WA) – \$0.099 per kWh**

But, the true cost of the end use of the electricity depends on the efficiency at which the work is being performed…

https://www.eia.gov/electricity/monthly/current_month/epm.pdf

The Cost of Energy

Since a kilowatt·hour ($3.6\text{x}10^6$ joules) costs around \$0.10kWh:

An <u>electric space heater</u> operates near 100% efficiency:

$36\text{x}10^6$ joules/dollar (heating)

An <u>incandescent light bulb</u> is less than 10% efficient:

$3.6\text{x}10^6$ joules/dollar (lighting)

<u>LED lights</u> can have operational efficiencies around 60%:

$22\text{x}10^6$ joules/dollar (lighting)

The Cost of Energy

A **<u>foot³</u>** of **natural gas** contains about 1.1×10^6 joules of energy.

Assuming that you utilize all of the energy contained in a foot^3 of natural gas, at an average cost of around $12 per 1000 foot^3, that equates to about:

$$92 \times 10^6 \text{ joules/dollar}$$

But, taking into account that gas furnaces have efficiencies ranging from 78% − 97%, at an efficiency of 90%, this equates to:

$$83 \times 10^6 \text{ joules/dollar (heating)}$$

This is 2.3x higher than the 36×10^6 joules/dollar cost for electric heat.

The Cost of Energy

A gallon of gasoline contains about 1.3×10^8 joules of energy.

- **assuming that you utilize all of the energy contained in a gallon of gasoline, at the current price of $2.50/gallon, that equates to about:**

$$52 \times 10^6 \text{ joules/dollar}$$

But, most gasoline engines have thermal efficiencies ranging from 20% − 25%. When accounting for friction and other losses, the average overall efficiency of a car drops down to 15% − 20%. At the high end of this range, this equates to:

$$10.4 \times 10^6 \text{ joules/dollar}$$

Energy Efficiency Savings

How many dollars per year would you save by replacing a 100W incandescent bulb with an 18W LED equivalent bulb if the bulb is used 8 hours per day?

Both bulbs produce ~1600 lumens of light

100W incandescent bulb:

$$100\text{ W}\cdot\frac{1\text{ kW}}{1000\text{ W}}\cdot 8\,\tfrac{\text{hours}}{\text{day}}\cdot 365\,\tfrac{\text{days}}{\text{year}}\cdot 0.10\,\tfrac{\$}{\text{kWh}} = \$29.20/\text{year}$$

18W LED bulb:

$$18\text{ W}\cdot\frac{1\text{ kW}}{1000\text{ W}}\cdot 8\,\tfrac{\text{hours}}{\text{day}}\cdot 365\,\tfrac{\text{days}}{\text{year}}\cdot 0.10\,\tfrac{\$}{\text{kWh}} = \$5.26/\text{year}$$

Savings: **$23.94 / year**

Units of Energy – Conversions

The following table provides conversion factors between the various units of energy:

convert to →	joule (J)	calorie (cal)	BTU	kWh	eV
joule (J)	1	0.2388	$9.48\text{x}10^{-4}$	$2.78\text{x}10^{-7}$	$6.242\text{x}10^{18}$
calorie (cal)	4.187	1	$3.97\text{x}10^{-3}$	$1.163\text{x}10^{-6}$	$2.613\text{x}10^{19}$
BTU	1055	252	1	$2.931\text{x}10^{-4}$	$6.585\text{x}10^{21}$
kWh	$3.6\text{x}10^{6}$	$8.598\text{x}10^{5}$	3412	1	$2.247\text{x}10^{25}$
eV	$1.602\text{x}10^{-19}$	$3.827\text{x}10^{-20}$	$1.519\text{x}10^{-22}$	$4.45\text{x}10^{-26}$	1

Note: 1 Nutritional Calorie (Cal) = 1000 calories (cal)

Sources of Energy

Energy comes from a variety of sources:

U.S. total energy statistics

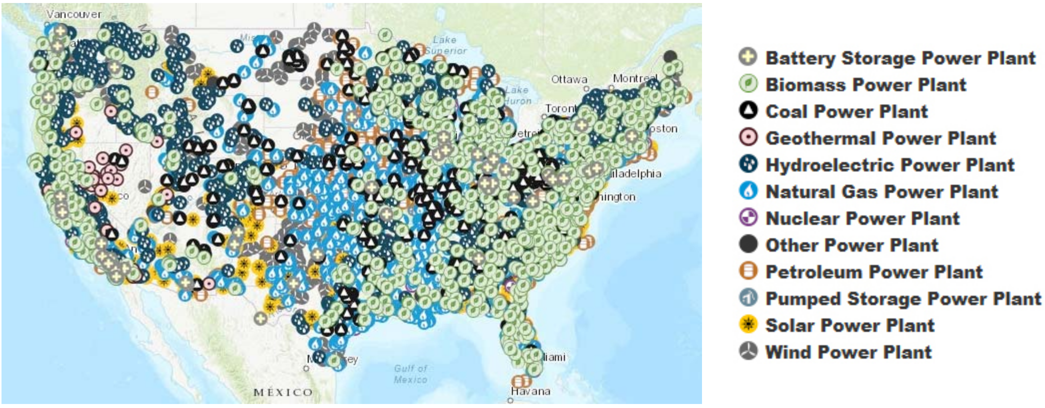
Preliminary data for 2017. Note: sum of share of totals may not equal 100% because of independent rounding.

Total primary energy production	87.54 quadrillion British thermal units
By fuel/energy source • Natural gas • Petroleum (crude oil and natural gas plant liquids) • Coal • Renewable • Nuclear	share of total • 32% • 28% • 18% • 13% • 10%
Total energy consumption	97.68 quadrillion Btu
By fuel/energy source • Petroleum • Natural gas • Coal • Renewable • Nuclear	share of total • 37% • 29% • 14% • 11% • 9%
Electricity generation	4.01 trillion kilowatthours
By major fuel/energy source • Natural gas and other gases • Coal • Nuclear • Renewables • Petroleum	share of total • 32% • 30% • 20% • 17% • 1%
Energy-related carbon dioxide emissions	5,142 million metric tons CO2
By energy source • Petroleum • Natural gas • Coal	share of total • 45% • 29% • 26%

https://www.eia.gov/

Sources of Electric Energy

Electric Energy Sources in the US:



Interactive map available at: https://www.eia.gov/state/maps.php?src=home-undefined

Non-Renewable Energy

Non-renewable energy is energy that is collected from finite resources that will eventually be depleted over time.

Non-renewable energy sources include:

- **Natural gas — gas formed from prehistoric decomposition**
- **Coal — carbonized material formed from prehistoric organic matter**
- **Nuclear energy — energy derived from nuclear fuels**
  - **uranium, plutonium**
- **Petroleum products — products refined from crude oil**
  - **hydroelectric energy, rollercoasters, etc.**
- **Hydrocarbon gas liquids — hydrocarbons that occur as gases at atmospheric pressure**
  - **propane, butane**

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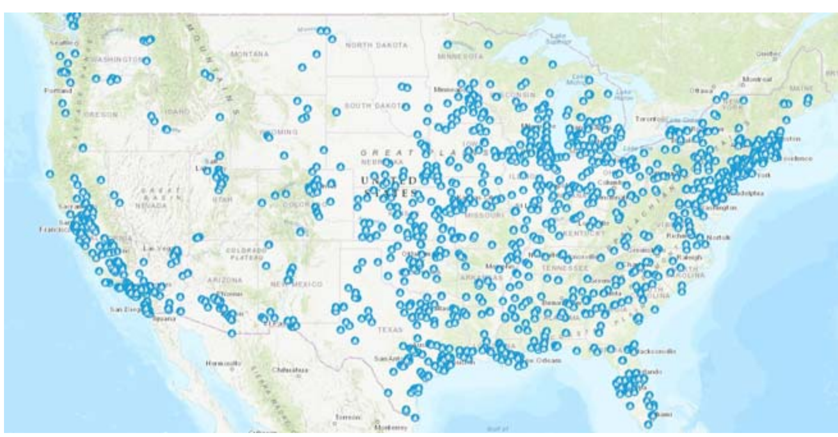
Non-renewable Electric Energy Plants

Natural Gas Plants in the US:



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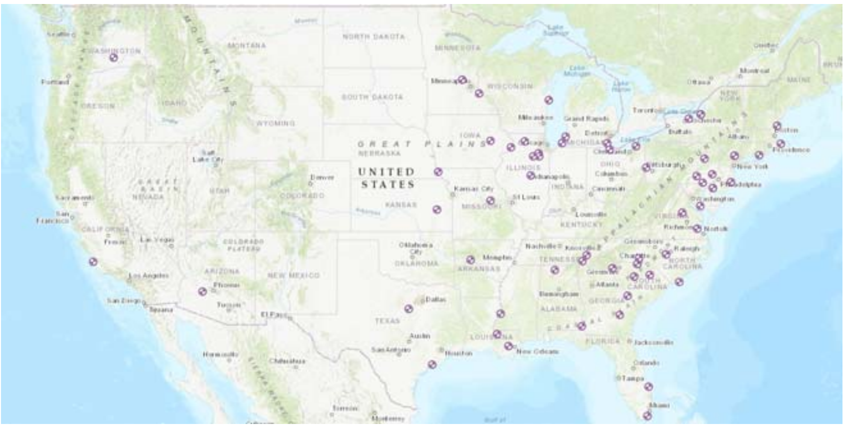
Non-renewable Electric Energy Plants

Coal Plants in the US:

https://www.eia.gov/

Non-renewable Electric Energy Plants

Nuclear Plants in the US:



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Renewable Energy

<u>Renewable energy</u> is energy that is collected from renewable resources, which are naturally replenished on a human timescale.

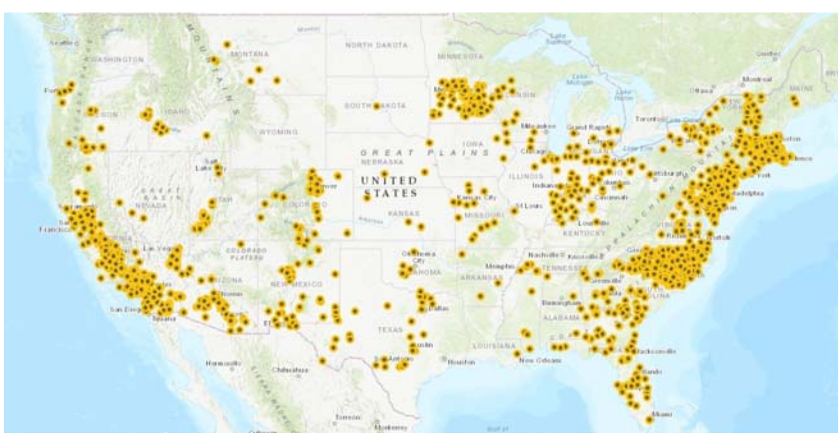
Renewable energy sources include:

- Solar Energy
- Tidal Energy
- Geothermal Energy
- Biomass Energy
- Wind Energy
- Hydro Energy
- Wave Energy

https://www.eia.gov/

Renewable Electric Energy Plants

Solar Plants in the US:



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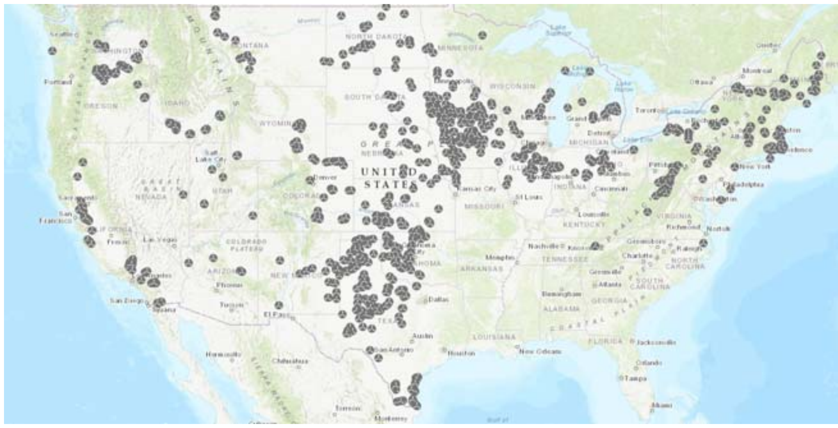
Renewable Electric Energy Plants

Wind Plants in the US:



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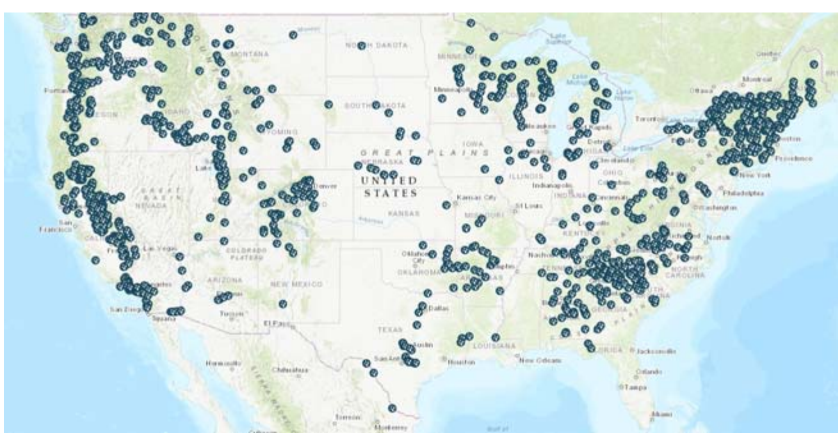
Renewable Electric Energy Plants

Hydro Plants in the US:



https://www.eia.gov/

Renewable Electric Energy Plants

Geothermal Plants in the US:

https://www.eia.gov/

Renewable Electric Energy Plants

Biomass Plants in the US:

https://www.eia.gov/

Sources of Renewable Energy

The three primary types of renewable energy are:

Solar, Tidal, and Geothermal.

Solar energy refers to energy from the sun that is converted into thermal or electrical energy. This energy arrives at the Earth in the form of electromagnetic radiation (sunlight).

Tidal energy refers to energy derived from the tides, which results from the gravitational pull of the moon and sun on the Earth.

Geothermal energy refers to energy derived from geothermal heat, which results from the decay of radioactive particles within the Earth and residual heat from gravitation during the formation of the Earth.

https://www.dictionary.com/browse/energy

Sources of Renewable Energy

Although typically considered other sources of renewable energy, the other four types:

Wind, Rain, Waves, and Biomass

are all sources of energy that result directly from the solar energy that reaches the Earth.

For example:

Wind energy is derived from the uneven heating of the surface of the Earth along with the accompanying transfer of water and thermal energy by evaporation and precipitation.

Introduction to Renewable Energy, Vaughn Nelson

Advantages of Renewable Energy

The advantages of renewable energy sources (in contrast to fossil fuels and nuclear materials) are that they are:

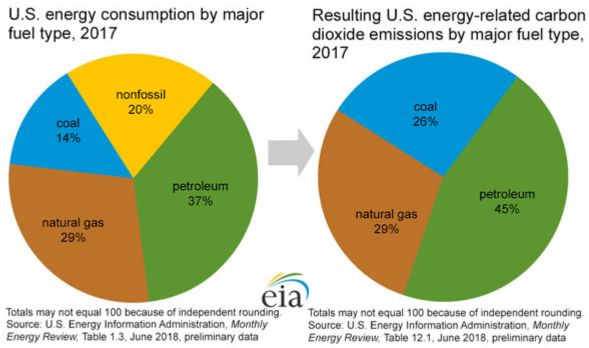
- sustainable (non-depletable),
- ubiquitous (found everywhere across the world), and
- essentially nonpolluting.

Furthermore, certain types of renewable energy systems, such as wind turbines and photovoltaic panels, do not need water for the generation of electricity, in contrast to steam plants fired by fossil fuels or nuclear power.

https://www.dictionary.com/browse/energy

Advantages of Renewable Energy

CO_2 emissions:



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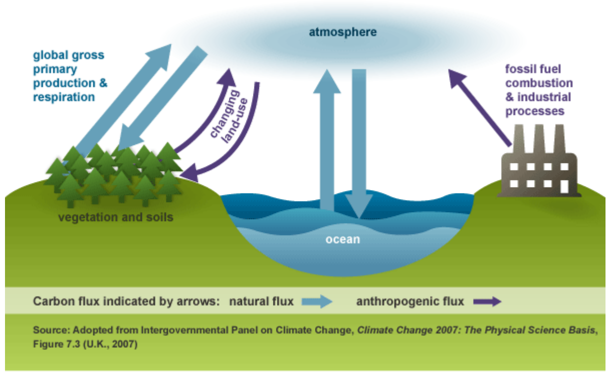
Global Warming

CO_2 emissions:



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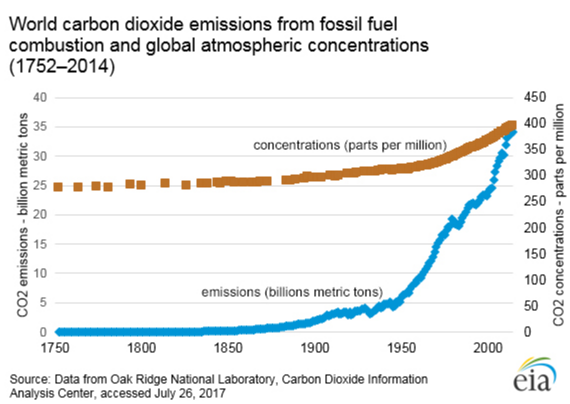
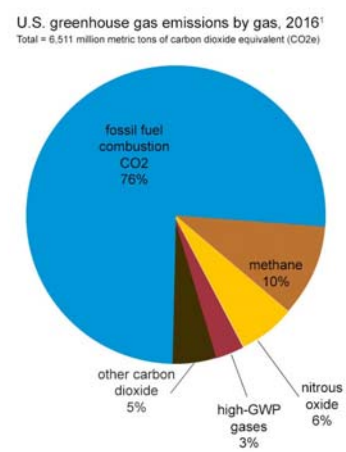
Global Warming

CO_2 emissions:





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