What is Energy?:

Etymology, from Greek: EN (at) + ERGON (work) = ENERGY

Began with knowledge of motion, heat, and light; people knew the different forms of energy could transform into one another.

We now have many forms of energy:

- motion
- heat
- light
- chemical (breaking of bonds between atoms)
- electro-magnetic
- nuclear (breaking of an atom’s nucleus)
- potential energy (storage)
- elastic energy (storage through springs, compressed air, etc.)

1st Law of Thermodynamics:

- energy is conserved
- any form of energy can be converted into any other form.

*But there are “higher” and “lower” forms; conversion is usually “higher” to “lower”

What is Heat?:

The motion of particles on a micro scale

The average of the motion of all the molecules is zero (no net movement).

Heat is different than ordered movement on the macro scale because the net motion is not zero (all the molecules move in some ordered fashion).
2nd Law of Thermodynamics:

- there is a net tendency of systems towards disorder
- “higher” forms of energy are more ordered

Units of Energy:

A Joule (J) is the standard unit of energy (named for James Joule, who was first to prove the 1st Law of Thermo.)

1 J = 1 kg * m²/s²  

Force = mass * acceleration

Energy = force * distance

Energy is equivalent to exerting a force over a finite distance, also defined as mechanical work (this makes sense since work and energy have the same units, a Joule).

What is Power?:

Power is work or energy over a finite time period, also known as a rate of energy generation or consumption.

* Remember that energy “generation” and “consumption” are actually just energy transformations. There is no way to create or destroy energy.

The unit of power is a Watt (named for James Watt, inventor of the first commercially really successful steam engine)

1 Watt = 1 J/s = 1 kg * m²/s²  

The Force of Gravity:

Force of gravity = mass * g

*g is a constant and is the acceleration of gravity at the surface of Earth, equivalent to 10 m/s².
To calculate the power required to do work against gravity, we need the force of gravity multiplied by the distance the mass travels, and then we need to divide by the time the work takes to get a rate (power).

\[
\text{Work} = \text{mass} \times g \times \text{distance}
\]

\[
\text{Power} = \frac{\text{Work}}{\text{time}} = \frac{(\text{mass} \times g \times \text{distance})}{\text{time}}
\]

**DEMO: What is a Watt?**

Hold 0.1kg weight and raise it 1 meter in 1 second \((g=10 \text{ m/s}^2)\). What power output of your arm required to do this?

\[
\text{Work} = 0.1 \text{ kg} \times 10 \text{ m/s}^2 \times 1 \text{ m} = 1 \text{ J}
\]

\[
\text{Power} = \frac{1 \text{ J}}{1 \text{ s}} = 1 \text{ W}
\]

The power required is one Watt.

Repeat with 1 kg mass \(\Rightarrow\) the energy required is 10 W.

Now compare this with a standard light bulb \((60 \text{ W})\). To put out as much energy as a light bulb, you would need to repeatedly lift 60 kg \((132 \text{ lbs on Earth})\) 1 meter in the air every second.

**3 Sources of Earth’s Energy Flows:**

1) **Solar** (radiation from nuclear fusion)
   This includes energy from hydro, wind, fossil fuels, and plants. This is the dominant energy source we
2) **Nuclear fission** (geothermal heat flux)
   This can be both the natural decay of radioactive elements in the Earth or the accelerated decay of elements in a nuclear reactor.
3) **Tidal Energy** (the Moon’s gravitational pull on Earth)
   The tides created by the gravitational pull of the Moon on Earth’s surface cause energy to be dissipated through friction, slowing down the Earth’s rotation
Calculating the Power Output of the Sun on Earth’s surface:

We want to describe the power at the surface of Earth in terms of a square meter of surface (Power/Area or W/m²).

To do this, we will use the evaporation and precipitation that occurs within 1 year on Earth’s surface.

Assumptions:

- The global average yearly precipitation is 1 m (estimated from precipitation graph shown in class). *(The actual value is 1.05 m/yr, so the class guess was within 5%)*

- The incoming solar flux (Fsolar with units of W/m²) is split equally between reflected and absorbed (Freflected = 0.5 * Fsolar and Fabsorbed = 0.5 * Fsolar).

- Of the absorbed light, 50 % is used for evaporation in the hydro cycle (Fhydro = 0.5 * Fabsorbed = 0.25 * Fsolar).

Since we would like to know the incident Power/area, lets also consider the precipitation/area, and make that area 1 m². With a precipitation amount of 1 m/year, we know that the sun’s power is enough to evaporate 1 m³/ year over a 1-m² surface.

Estimating the Power required for evaporation:

Consider a microwave with a power output of 1000 W. If you put a liter (L) of water in it (remember there are 1000 L of water in a m³), how long will it take for the 1000W microwave to evaporate it?

*for the purposes of our calculation, assume the water is put in at just below the boiling point. We assume this because we are only interested in the energy per unit mass required for the liquid to turn to water vapor (i.e. the latent heat of vaporization), not the
energy per unit mass required to warm the water to the boiling point (i.e. the specific heat capacity).

The class estimated 30 minutes for the water to evaporate.

30 min * 60 sec/min = 1800 seconds

How much energy does evaporating the water in 1800 seconds take?

\[
\text{Energy/L} = 1000 \text{ J/s} \times 1800 \text{ s} \approx 2 \times 10^6 \text{ J/L}
\]

We now have the energy required to evaporate a liter of water.

(And we have a good indication of how good these estimates are – the real value of the latent heat of vaporization of water is 2.26*10^6 J/l, so the thought-experiment estimate was within 15% of the real value).

To apply this to our problem, we need to convert the energy into a power (energy/time).

First, convert L to m^3 because the amount of water we are interested in (the precipitation over 1 m^2 of surface area) is in m^3.

\[
\text{Energy/m}^3 = 2 \times 10^6 \text{ J/L} \times 1000 \text{ L/m}^3 = 2 \times 10^9 \text{ J/m}^3
\]

Using this number, the fact that on Earth it takes 1 year to evaporate a m^3 volume of water, and the fact that there are \(~4 \times 10^7\) s/year (365 days/yr * 24 hr/day * 3600 s/hr), we can find the power incident per square meter.

\[
\text{Power} = (2\times10^9 \text{ J/m}^3) \times (1 \text{ m}^3/ \text{ year}) \times (1 \text{ yr/}4\times10^7 \text{ s})
\]

\[
\text{Power} \approx 50 \text{ W}
\]

Since the m^3 of water we are evaporating is per 1m^2, the power we just calculated is a power per m^2.
Therefore, $F_{\text{hydro}} = 50 \text{ W/m}^2$

To find $F_{\text{solar}}$, remember that we assumed $F_{\text{hydro}} = 0.25 \times F_{\text{solar}}$. Therefore, we have estimated that $F_{\text{solar}} = 200 \text{ W/m}^2$.

*Reality check: when compared to the figure shown in class, this is a fairly accurate estimate (see “Earth’s Energy Flow” figure on the web page, which shows the radiation incident at the earth's surface (absorbed + reflected) as 198 W/m$^2$).*