

Questions

1. Apart from visible light, write down the names of three parts of the electromagnetic spectrum and describe a way in which we use each of them. (You needn't limit your responses simply to energy consumption.)

Solution: Here is a partial list...

Radio: broadcast TV and radio signals

Infrared (IR): keeping hamburgers warm under a "heat lamp"

Ultraviolet (UV): killing bacteria

X-Rays: medial imaging

2. Why are wind and hydrological energy considered forms of solar energy? Describe a type of hydrological energy that is not a form of solar energy.

Solution: The winds are largely driven by differences in temperatures at the Earth's surface. These temperature differences are the result of uneven warming due to the Sun. Hydrological energy in the forms of dams is the conversion of gravitational potential energy into electrical energy. The water gains the gravitational energy by evaporating, floating upward then precipitating down on a region that is at a higher elevation. Most of the energy responsible for the evaporation and transportation comes from the Sun.

The majority of the tidal energy available comes from the gravitational interaction between the Earth and the Moon (a small fraction is also due to the gravitational interaction between the Earth and the Sun.)

3. What is the difference between active solar energy systems and passive solar energy systems? Given an example of each kind.

Solution: Active systems rely on some intermediate electromechanical technology to convert sunlight into another usable form of energy, generally electricity. An example is a photovoltaic solar cell.

Passive systems are ones that do not require an intermediate technology; they run on a heat "sink" that naturally absorbs the sun's rays. An example is a floor in a room with a big, south-facing window.

4. Solar, wind, and hydroelectric power have many obvious advantages over fossil fuels. However, these alternatives have significant problems, too. Briefly describe three drawback or limitations for each of aforementioned alternative energy sources.

Solution:

Solar – expensive; sunlight is intermittent at best; and energy generated is electrical, so it must be moved around via power lines.

Wind – expensive; wind turbines are large and noisy; wind is intermittent at best, too; in some heavily populated locations just not feasible; and energy generated is electrical, so it must be moved around via power lines

Hydropower – dams have a very limited lifetime; cause major disruptions to riparian ecosystems; and energy generated is electrical, so it must be moved around via power lines

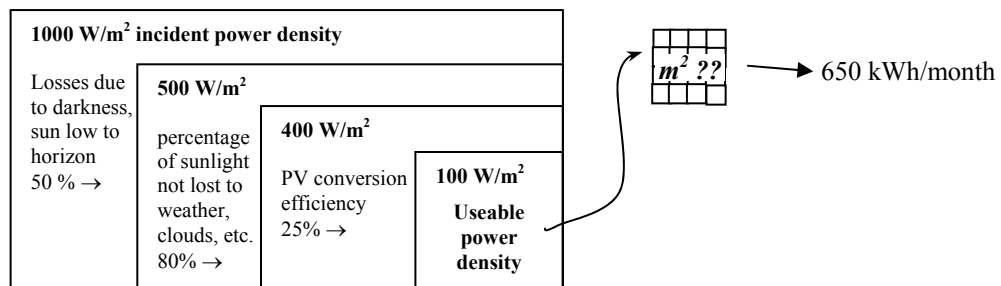
5. The central area of North America has been referred to as the "Saudi Arabia of wind energy." Explain why this characterization is reasonable. Also, explain the limitations of this metaphor.

Solution: The central area of North America has an enormous amount of "tap-able" wind energy. So, like Saudi Arabia, which has the most oil, central area of North America has the most wind energy. Limitations to the metaphor include that wind is a renewable resource, so we will not run out of wind. Also, unlike oil wind energy is not easily transported.

Problems

6. A small home may use 650 kWh/month of electricity. The owners are planning to "get off the grid" by installing a photovoltaic solar array on their property. How many square meters of solar panels will they need to meet their monthly energy consumption? Compare this area to the area of something that is comparable in size. (For example, if they needed 2 m² of solar panels, then you could say that's about the area of a large tabletop.)

NMR:



Knowns: Home's energy consumption is about 650 kWh/month

The remainder of "knowns" and assumptions are hard to distinguish in this problem

Unknowns: How many m² of PV cells we'll need to fully cover the average monthly energy consumption.

Assumptions: Surface insolation is 1000W/m²

you can only capture about 50% of that because of darkness or sun's angle above horizon

clouds and weather obscure about 20% of the "good" sun

the cell's conversion efficiency is about 25%

all of the cell receive the same amount of sunlight

a month is 30 days

SOP: The amount of power supplied is proportional to the rate at which power is supplied and the area of the collector. The total energy is proportional to the power and the time

Equations: Amount = rate × area

Power = energy/time

Solution: From the NMR we've got about 100 W/m² = 0.1 kW/m² = (0.1 kJ/s)/m², so the cells collect...

$$\frac{0.1 \text{ kJ/s}}{\text{m}^2} \cdot \frac{3600 \text{ s}}{\text{hr}} \cdot \frac{24 \text{ hr}}{\text{day}} \cdot \frac{30 \text{ day}}{\text{month}} = \frac{2.6 \times 10^5 \text{ kJ}}{\text{m}^2 \cdot \text{month}}$$

And the house requires...

$$\frac{650 \text{ kWh}}{\text{month}} = \frac{(650 \text{ kJ/s}) \cdot \text{hr}}{\text{month}} \cdot \frac{3600 \text{ s}}{\text{hr}} = \frac{2.34 \times 10^6 \text{ kJ}}{\text{month}}$$

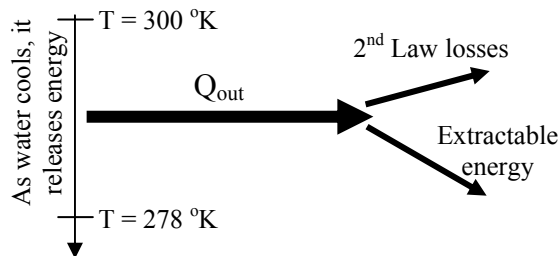
So to cover this demand we would need...

$$\frac{\frac{2.34 \times 10^6 \text{ kJ}}{\text{month}}}{\frac{2.6 \times 10^5 \text{ kJ}}{\text{m}^2 \cdot \text{month}}} = 9 \text{ m}^2$$

This is comparable to a large table.

7. Determine the amount of energy/kg that could be extracted from 1 kg of water cooling from 27 °C to 5 °C.

NMR:



Knowns: T_H = 300 °K, T_C = 278 °K

The specific heat of water is 4186 J/(kg °C)

Unknowns: How much energy can be extracted/kg of water cooled between these two temperatures

Assumptions: Not additional heating is done on the surroundings beside minimum amount required by the 2nd Law of Thermodynamics

SOP: The heating is proportional to the mass, the specific heat, and the change in temperature, the amount of energy that can be extracted is limited by the Carnot efficiency

Equations: Q = msΔT, e = (T_H - T_C)/T_H

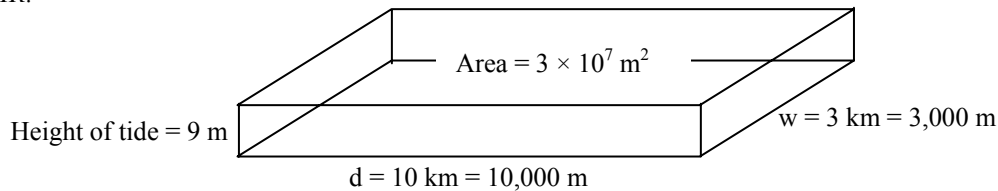
Solution: Q = 1 kg × 4186 J/(kg °C) × (27 °C - 5 °C) = 92 kJ/kg

e = (T_H - T_C)/T_H = (300 °K - 278 °K)/300 °K = 0.073

Useful energy = eQ = 6.75 kJ/kg

8. Consider the construction of a tidal installation near Passamaquoddy, New Brunswick, Canada. If the basin is 3 km wide and 10 km long, and the tides rise 9 m over the low tide height, how many MW_e will this project produce? Will this plant produce as much electricity as, say, a large coal-fired plant?

NMR:



Knowns: The height between the low and high tide surface is 9 m
The basin is 10 km = 10,000 m across and 3 km = 3,000 m wide
The density of water is 1030 kg/m³
g = 9.8 m/s²

Unknowns: How much energy is stored in that much water, how much power can be extracted

Assumptions: The tide rolls in and out twice/day (it's not exactly that)
The conversion efficiency is about 20%

SOP: The energy stored in a tidal basin is proportional to the area of the basin, the density of the water, and the square of the tidal height.

Equations: $E = \frac{1}{2} (\text{density})(\text{area})(g)(h^2)$, power = energy/time

Solution: When full, the tidal basin contains...

$$E = \frac{1}{2} \times 1030 \text{ kg/m}^3 \times (3 \times 10^7 \text{ m}^2) \times 9.8 \text{ m/s}^2 \times (9 \text{ m})^2 = 1.2 \times 10^3 \text{ J} = 1.2 \times 10^7 \text{ MJ}$$

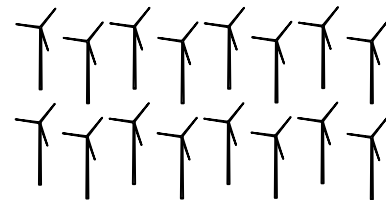
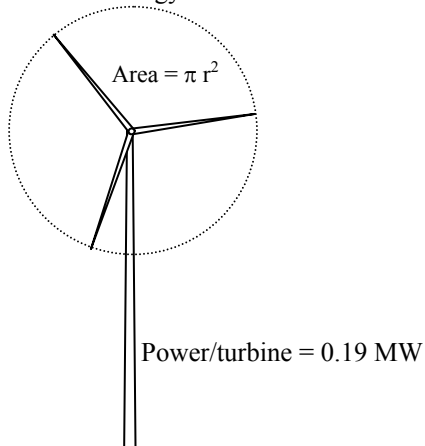
Since this happens twice/day, we have a total amount of energy available to us of $2.4 \times 10^7 \text{ MJ/day}$. This is an average power of...

$$\frac{2.4 \times 10^7 \text{ MJ}}{\text{day}} \cdot \frac{\text{day}}{24 \text{ hr}} \cdot \frac{\text{hr}}{3600 \text{ s}} = 284 \text{ MW}, \text{ which is a lot, but at a 20\% conversion efficiency that's}$$

only about 57 MW_e. Sill, that could power a small city. A large coal-fired plant produces about 1000 MW_e.

9. In areas with “outstanding” wind power potential, the wind has an energy density of 600 W/m² at a height of 50 m above the ground. Imagine erecting wind turbines in that area that have a blade length of 10 m (measured from the axis out to the tip of the blade). How many wind turbines would you need to supply the energy needs for a small city? Say about 1200 MW. Explain why your calculation is an underestimate of the actual number that would be needed to provide that much energy.

NMR:



How many turbines for 1200 MW?

Knowns: The blades are 10 m long
The wind energy density is 600 W/m²

Unknowns: How many wind turbines we'd need to produce 1200 MW

Assumptions: The wind blows all of the time
All of the wind energy is converted to electrical energy

SOP: The energy captured is proportional to the area of the blades and the density of the energy

Equations: Amount = energy density × area

Solution: Amount = 600 W/m² × (3.14 × (10 m)²) = 1.9 × 10⁵ W/turbine = 0.19 MW/turbine

So we need 1200 MW/0.19 MW/turbine = 6366 turbines

This is a gross underestimate of the number. Why? The wind doesn't blow steadily, and no single turbine catches a significant fraction of the available energy, not to mention the conversion efficiencies that I didn't include.