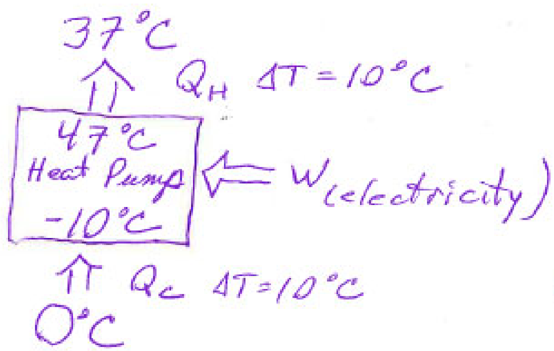
Assessment #6.

1) Nate Heston (Cal Poly Physics, Return Peace Corps Volunteer from Ghana) and I conduct research on DDS (direct DC Solar) ice making, whereby during the day, solar electricity directly drives a freezer, which stays cold during the night with no power. We are deploying a freezer this summer in Agbokpa, Ghana, on the shore of Lake Volta. During the day, the temperature is about 37°C and we want to make ice. A 10°C temperature difference is needed to drive heat from the ice to the freezer and from the freezer to ambient. Let's say we can make a *perfect* Carnot cycle.

   a) If I want to remove 100 MJ of heat from the ice, how many kWh of electricity will it require?



$\Delta T_{heat\ pump} = 57°C$

$\eta_{Carnot} = \frac{T_c}{T_H - T_c} = \frac{263\ K}{57\ K} \approx 5$

$Q_c = \eta W \Rightarrow$

$W = \frac{Q_c}{\eta} = \frac{100\ MJ}{5} \frac{kWh}{3.6\ MJ} \approx 6\ kWh$

   b) Why can't I hope to make a perfect Carnot cycle? There are two common incorrect answers to this question (1) because there's friction. This is true a true statement and there is friction, and if you had a perfect Carnot cycle, it would still not give you the ideal Carnot efficiency. But that's not what the question asked. (2) "because entropy limits your efficiency". This is also true, but the Carnot limit results from exactly that consideration – what if the change in entropy is zero?

      ⇨ The answer is that a Carnot cycle is comprised of adiabatic and isothermal processes because each of these results in no change in entropy: (change in entropy = Q/T). In an adiabatic process, Q = 0. In an isothermal process, T is the same for both sides of the heat flow so the entropy gained by one body = entropy lost by the other. However, this is not the thermodynamic cycle of the refrigerator. We could try to make one, but then in order to have an isothermal compression (or expansion), we would need heat to flow across a boundary where dT = 0. Such a process would take infinitely long. So, in a practical sense, in order to make a refrigerator (and heat engine) put out any amount of power (or deliver a non-zero heat flow), we need to compromise the efficiency.

   c) How can I use the proximity of Lake Volta to my advantage?

You could put the cooling vents inside the lake to more efficiently make Ice by lowering T_H and improving heat dissipation, thereby lowering Δt_c as well.

The lake gives you two things that will improve your COP (see drawing for part A above). It will reduce the temperature of the hot side because the water is likely cooler than the air, especially during the day. Additionally, water has a much higher specific heat and thermal conductivity than air, and thus the dT for water would likely be considerably less than 10ºC. Both of these things would lower the temperature of the heat pump hot side, and thereby increase the COP.

2) My neighbor buys a wind turbine that can generate 1 kW on a crisp windy day. Not to be outdone in the "most sustainable person in the neighborhood", I buy the next model up! The blades on my turbine are three times as long as my neighbor's model and it's way way higher, so the wind it samples are twice the speed of my neighbor's!
   a) Estimate the power that my turbine will produce.
   b) Describe to me in terms of basic physics why I can't design a wind turbine that is 100% efficient in extracting energy from the wind it samples.
   c) Explain why my spirit of competition may be counter-productive toward global sustainability even if the competition is for "most sustainable".

a) $P = \frac{16}{27} \cdot \frac{1}{2} \rho A \cdot V_{air}^3$ ~~Neighbor~~

$A = \pi r^2$ $A = 9 \times$ neighbor

$v^3 = 8 \times$ neighbor

A

$(9)(8)\ 1kW = 72\ kW$ ✓

b) For a wind turbine to be 100% efficient, that would mean that 100% KE of the air would have to be transferred to the turbine and thus the air would have to stop moving — can't happen. ✓

($P \Rightarrow 0$)

c) You won't want to work with the community to become a sustainable community as a whole because you, yourself wants to be the best.

- I don't fully agree with ↑ though because if everyone is trying to be be better, the community is going to become pretty sustainable.

2a. $1\,kW = \frac{1}{2}\rho v^3 \cdot A$ (same) $2v \overset{\text{cubed}}{=} 8\,KW$ $3\ell \overset{\text{squared}}{=} 9\,Kw$ **72 KW**

b. Betz limit is 59%, no higher can be reached.
Why? The wind will be slowed by the turbine blades to some degree, so it will be impossible to get higher than 59%

C. The spirit of competition drives people to acquire more/bigger things, even if unnecessary. This is wasteful, even if those "things" are wind turbines or electric cars. Also, by outcompeting others, it discourages them from attempting to match up, such as with the helicopter date. By having the largest wind turbine on the block, it may discourage the block from attempting to compete, even if some were considering moving to wind energy with a smaller turbine. In all, cooperation is much more necessary in moving towards global sustainability.