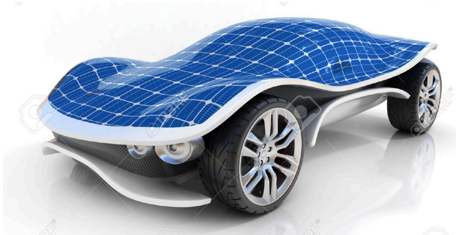
1 Three ideas for the term project

Read the description of the term project on the class website at "Introduction to term project". Identify three (3) subjects that you find interesting/intriguing (for example, solar energy, exoplanets, ...). Within each subject, pose a question that might have an interesting quantitative answer: "Since it requires energy to make a solar panel, how long does it take to recoup that energy?", "How far away could we see an Earth-like planet orbiting a Sun-like star?" ... You should turn in 3 different subjects and 3 different quantitative questions (quantitative means "quantities that can be calculated and/or measured")

Let your mind wander as broadly as possible. Subjects and questions are not restricted to the topics taught in PH315. During this exploratory stage, be bold and daring; you are not committing yourself to solve all 3 questions. To spark your imagination, there is a list of ideas on the class website. The instructor will read your ideas and give you feedback. Whenever possible, the feedback will point you towards a coarse-grained model that is helpful for answering your question. Use the feedback to help decide which question you will develop further (or whether you need to go back to the drawing board).

2 Speed of a solar car

This self-driving solar car is travelling on a flat road on a windless day. The sun is directly overhead.



(a) Draw an energy flow diagram to describe the system. An arrow at the top of the flow diagram will represent incoming solar energy (landing on the solar panel). One circle will represent the solar panel, and one circle will represent the electric motor. Label each arrow with quantitative values of the energy flow (joules per second).

(b) Estimate how fast this self-driving solar car can travel on a flat road on a windless day when the sun is directly overhead. Give you answer in meters per second.

Use the following parameters for the system:

- The car is 1.8 m wide, 1 m tall and 3 m long. The top surface of the car is entirely covered with solar panels.
- The sun is directly overhead and the intensity of the sunlight is 1000 J/(s.m^2).
- The electric motors are powered directly by the solar panels (no battery power).
- The solar panels convert sunlight energy into electrical energy with 20% efficiency (the other 80% of sunlight energy is heating the solar panel).
- The electric motors convert electrical energy into mechanical work with efficiency 90% efficiency.
- The drag coefficient is 0.2.

- The energy dissipation associated with the tires rolling on the road can be neglected.

3 Hot showers and standard deviation

(a) Estimate the energy used during a typical 10-minute shower in the United States. The dominant variables in this problem are the temperature rise of the water and the flow rate of the showerhead. Develop a coarse-grained model that incorporates these two variables. For simplicity, you may assume: (i) The water heater is 100% efficient at converting electrical energy into heat, and (ii) the water heater is located close to the shower, so heat losses in the pipes can be neglected.

(b) Develop a reasonable estimate for the standard deviation of your answer to part a. That is, imagine measuring the energy used for a 10-minute shower in a thousand randomly selected U.S. households. How much would the energy use vary? To develop a reasonable estimate, spend a little time doing internet research (or in-person research) on the variability of shower flow rates, the variability of ground temperature, and the variability of shower water temperature (personal preference). Once you can justify reasonable numbers for the variability of these inputs, propogate the uncertainty through your coarse-grained model using the methods we discussed in class.

(c) **Sense making:** Compare the typical energy used for a 10-minute shower to the typical energy used to drive an elecric car at 70 mph for 10 minutes.

4 Gasoline Sun

(a) Electromagnetic radiation energy from the Sun arrives at the upper atmosphere of our planet at a rate of about 1350 J/(s $\cdot$ m^2). Use this information, together with the average radius of the Earth's orbit, to show that the Sun radiates energy at a rate of about 4×10^{26} J/s.

(b) We know from radiometric dating of rocks on Earth (and the Moon and Mars) that our solar system is about 4 billion years old. Let's make a naïve hypothesis (like scientists did in the early 1900s) that the Sun is powered by burning hydrocarbons. What mass of gasoline would be needed to power the Sun at a rate of 4×10^{26} J/s for 4 billion years? Compare to the actual mass of the Sun.

Note: The energy density of hydrocarbon fuels, including gasoline, natural gas, dry logs of wood, chocolate, croissants, gummy bears, etc. etc. is ≈ 40 MJ/kg.