1 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 · 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.

2 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.

You will also need: The specific heat of water is $c = 4200$ J/(K·kg).



(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.

3 Wave energy

The ocean swell lifts water against the force of gravity and makes water move in circular patterns. Energy can be harvested from this ocean swell: gravitational potential energy and kinetic energy are both available (see Chapter F of MacKay). Imagine I draw a line in the ocean that magically absorbs all of the energy associated with the swell, effectively flattening the waves.

If the line is parallel to the crest of the waves and has length L, the time-averaged rate that energy must be absorbed to flatten the swell (*energy* per *time*) is

$$\text{energy per time} = \frac{1}{4}\rho g h^2 v L \tag{1}$$

where ρ is the density of water, g is acceleration due to gravity, h is the height of the wave crest compared to flat water, v is the velocity of the wave crest. This equation is derived on page 307 of *Sustainable Energy* by David McKay.

A real device for harvesting wave energy can achieve an efficiency

$$\text{efficiency} = \frac{0.5 \text{ J (electrical energy)}}{1 \text{ J (wave energy)}} \tag{2}$$

Assume that typical Oregon deep-water waves have $v = 15$ m/s and $h = 1$ m. Estimate the electrical power that Oregon could capture if we built wave farms along the entire coast. Give your answer in J/s. There is 10-20% uncertainty in the estimates of v and h, so the precision of your calculation and final answer should be consistent with respect to this uncertainty.

Sense-making: Make a Comparison—Divide your answer by the population of Oregon. How does the wave energy production rate compare to the rate that people are using energy (see the class notes from Conservation of Energy: First Law of Thermodynamics)?

4 AI data centers energy usage in 2026

AI data centers are operating and under development widely in the year 2026. A global data center tracker shows a known power capacity of 67000 MW in total. This includes some data centers that are not yet operational, but *excludes* some operational data centers for which power capacity is not reported. For rough estimation purposes, let's assume these effects balance out and the reported total is a good estimate for the current power capacity of AI data centers globally.

To begin building a coarse grained model of the energy flow, let's assume that all energy used by AI data centers are powering a major use-case of AI today: user prompting of AI models. Here is a rough sketch of an energy flow diagram:

[Energy from data centers] —(100%)—> [Energy used in prompting AI]

The energy used in a single prompt was estimated in 2025 to be about 0.3 Wh (Watt-hours).

(a) What are at least 2 assumptions we are making as we build this coarse-grained model for the energy usage of AI data centers?

(b) Based on the coarse-grained model, estimate the average number of AI prompts one person uses per day.

(c) *Sense-making:* Does this number make sense based on what you expected to find? If not, what is an idea you have for improving the coarse-grained model?