Reminder: scientific ethics and significant figures

Significant figures in an answer are not only a numerical solution to a problem, but also a claim of confidence about the accuracy and precision of that solution.

Since we will do a lot of estimating in this class, we will need to keep significant figures in mind and not assert more confidence in an answer than we are reasonably able to, given the nature of estimation.

Concepts from Problem Set 2:

First problem
We found a safety factor of about one, indicating that yields must be higher than we assumed.

Plants are more calorically efficient to eat than meat.

Land is a limitation given that we have a finite solar flux W/m²; “spatial efficiency” matters.

Second problem

Energy density by mass J/kg is similar for gasoline and cooking oil.

Energy density by mass or volume is a limitation when considering fuels to utilize in various applications.

Example: batteries are much less energy dense than gasoline, so to get the same amount of energy, you must carry much more weight in batteries than you would in gasoline. Therefore, electric cars with batteries might just be feasible, but battery powered airplanes are impossible right now given the amount of extra weight they would have to carry.

Gasoline is remarkably energy dense.

Third problem

Bikes have a greater effective mpg than cars, but when we take into account the mass of a car vs. a bike, their mpg are comparable and cars can actually be better.

The human engine and auto engine are similar.

Review from last time: agricultural productivity

Average land per person global average is 20,000 m².

Of that, 2,500 m² per person is arable.

The amount of land required to feed a person on average is actually smaller if we look at modern, “high efficiency” yields.

Corn is remarkably productive, potatoes are also relatively productive and wheat is about 1/3 of corn.

Average land/person in US is 30,000 m².
US has relatively high arable land per person:

<table>
<thead>
<tr>
<th>Country</th>
<th>Arable land/capita m²</th>
<th>Arable land/capita %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRC, potentially arable</td>
<td>43,000</td>
<td>50</td>
</tr>
<tr>
<td>DRC, utilized</td>
<td>2,500</td>
<td>03</td>
</tr>
<tr>
<td>Canada</td>
<td>1,500</td>
<td>05</td>
</tr>
<tr>
<td>Russia</td>
<td>8,500</td>
<td>07</td>
</tr>
<tr>
<td>United States</td>
<td>6,000</td>
<td>19</td>
</tr>
<tr>
<td>World average</td>
<td>2,600</td>
<td>13</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>1,400</td>
<td>02</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>500</td>
<td>55</td>
</tr>
</tbody>
</table>

**Fossil fuels and the solar flux**

For the most part, incoming solar flux = outgoing infrared radiation

Chemical energy in plants is emitted as infrared radiation from heat of decomposition when plants die; the overall IR radiation of the Earth is smaller by a tiny amount due to the fraction preserved as fossil fuel

However, if not all plants decay, then input > output

This imbalance is preserved as an energy-rich, oily substance

Fossil fuel is a stored, fatty deposit from this energy imbalance; we are currently "burning off" this deposit

Sustainability is often framed as a moral standpoint; in physical terms, however, sustainability will happen when this deposit is completely burned off (~200 years from now?), so the question is rather how do we want to transition to this state?

**Modern per capita energy use**

Preindustrial energy consumption in food per person is ~100W

How much more per person are we using for non-food uses like heating, electricity, etc.?

For Americans, energy consumption per person is ~10,000W, 2 orders of magnitude higher (100W * 10^2 = 10,000W)

Since a person power is about 100W, this is like each American having 100 people helping us for daily life—washing, cooking, transportation, etc.

April 6, 2 of 3
History of technology: how did we go from 100W to 10,000W energy consumption per person?

See Vaclav Smil chart of energy consumption partitioned by use through the ages
Energy for food remains about the same today from 10,000 BC
Manufacture of items jumps in energy use in late 18th, early 19th centuries
Transportation eventually jumps, but lags behind manufacture of items
Slide images: Encyclopedia of Diderot and d’Alembert shows pictures of the state of work at the time
Animal power for pulling a plough only stopped being used in the mid-20th century
Oxen have more torque than horses, ability to pull more at a speed
Animal power was also used for rotation to grind things
Human powered wheels were used when greater precision was needed, for example, to turn a lathe where speed of turning was important (Encyclopedia of Diderot and d’Alembert)
Now electric motors spin most things for us
Wind and water were primary source of rotational and kinetic energy for a long time
Windmills used to be oriented with a vertical axis; eventually most windmills transitioned to a horizontal axis
Why? The horizontal axis proved more efficient; however, more sophisticated technology like gears had to be introduced to allow energy to be redirected for use
Also, horizontally oriented windmills had to be able to turn to match wind direction
Why are there so many windmills in the Netherlands? Pumping water to reclaim land
Rotational mechanical motion was converted to linear motion very early in industrial history using a device called a cam

Key idea: wood was burned to heat kilns, boil water, etc. but it was not used for making mechanical motion—there was no crossover
“Lack of energy was the major handicap of the ancien regime economies…” —Braudel
18th century industrial impasse, only two energy conversions:
Mechanical energy → mechanical motion using water and wind
Chemical energy → heat using wood
At that point, there was no way to use chemical energy other than through flesh