Biomass

Physics and Mathematics of Sustainable Energy

College of the Atlantic. November 8, 2022

1. In 2016 passenger cars in the US drove a total of 3.21 trillion miles[1] and the average fuel efficiency was 24.7 mpg[2].

   (a) How much fuel is used in the US by all cars in one year?

   (b) Suppose we wanted to replace all of this gasoline[3] with ethanol derived from US corn? How much land would be required? Express this area in some way that makes sense.

   (c) Suppose we wanted to replace all of this gasoline with ethanol derived from Brazilian sugar cane? How much land would be required? Express this area in some way that makes sense.

   (Note, btw, that this doesn't include the fuel used for trucks and planes.)

2. To heat an average home in Maine requires approximately 540 gallons[4] of fuel oil per year

   (a) How much thermal energy does this fuel oil produce? Answer in BTUs and kWh.

   (b) What power does this correspond to?

   (c) Suppose that you decide to heat your house with wood. Assume that the efficiency of your woodstove will be the same as the efficiency of your oil furnace.[5] How much land would you need to get this amount of power? See the data on the other side of the page. (Let's generously use 0.5 W/m^2 for Maine.)

   (d) There are very roughly half a million homes in Maine (`http://www.census-charts.com/HF/Maine.html`, accessed November 6, 2017.) How much land would be needed if all of Maine was to heat with wood? Put this number in perspective. Is this a little or a lot? What fraction of Maine is this?

3. Convert 150 GJ/ha y to W/m^2.

Some useful info:

- Corn ethanol in the US produces 900 gallons per hectare with an NER of 1.3.
- Sugarcane ethanol in Brazil produces 1800 gallons per hectare with an NER of around 9.
- One hectare is $10,000$ m^2.
- Calorific value of ethanol: 75,600 BTU/gal.
- Calorific value of pure gasoline (petrol): 115,000 BTU/gal

[1] `https://afdc.energy.gov/data/10315`

[2] `https://www.reuters.com/article/us-autos-emissions/u-s-vehicle-fuel-economy-rises-to-record-24-7-mpg-epa`

[3] The calorific value of ethanol is significantly less than that of ethanol, meaning that the "gas" mileage for a car running on pure ethanol will be perhaps as much as 40% less than using pure gas. But to simplify our calculation, let's pretend that their mileages are the same. (Although if engines were optimized for ethanol, their mileage might be better than it would have been for gas.)

[4] `https://www1.maine.gov/energy/fuel_prices/heating-calculator.php`, accessed November 6, 2017.

[5] This might not be a super assumption, but since in what follows we're interested in getting a very rough estimate, I think this assumption is ok.

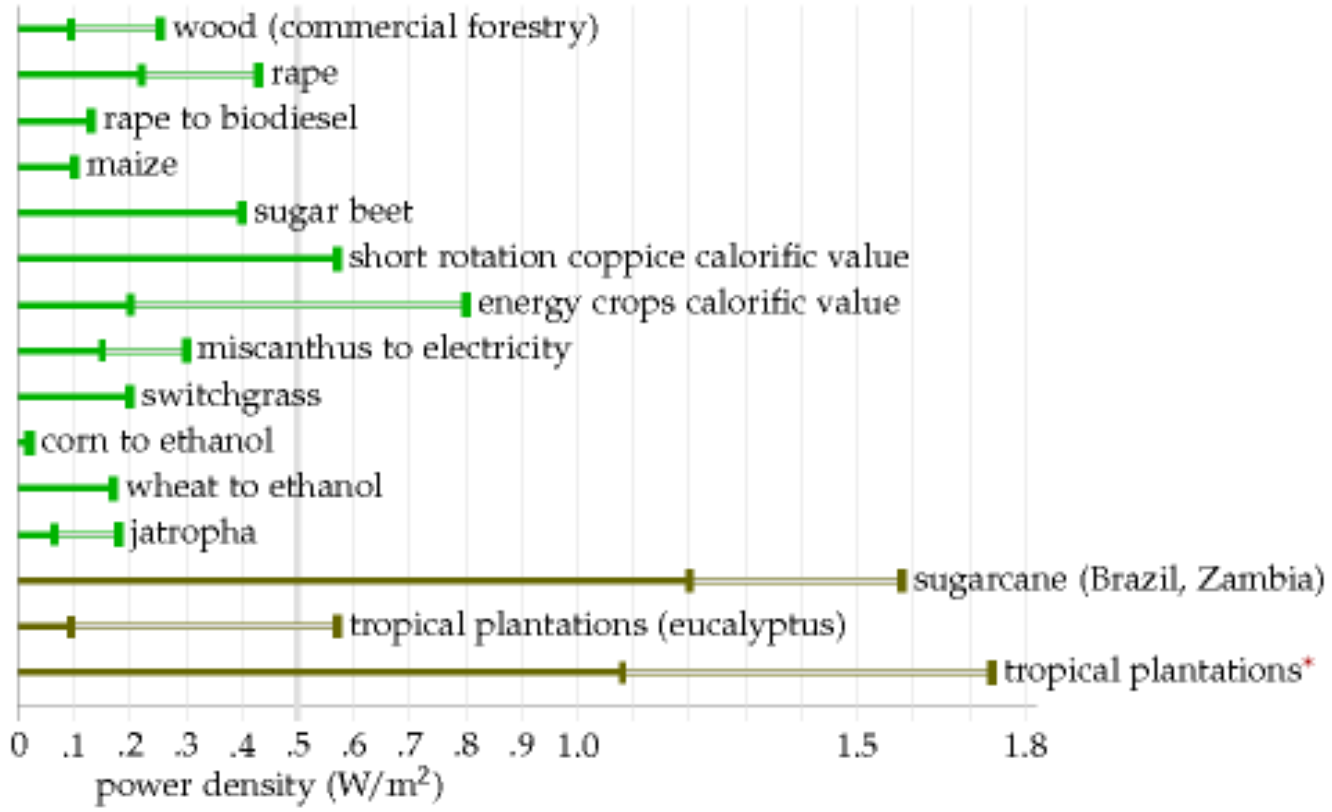

Figure 1: Power production for various crops. The three crops on the bottom of the figure are grown in tropical regions. The rest are for NW Europe. Figure from Sustainable Energy Without the Hot Air, David McKay, 2008.

Some data from Jaffe, Robert L., and Washington Taylor. The physics of energy. Cambridge University Press, 2018, p. 500, for corn grown in the US.

- Yield: 10t/ha y.
- Energy density of corn 15 MJ/kg
- Energy Capture rate of 150 GJ/ha y
- In 2013, 350 Mt harvest on 35Mha of land.
- 30% of corn used to make ethanol, 40% consumed by livestock, 10% turned into corn starch, oil, and high-fructose corn syrup.