Energy conversion

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The process by which carbon dioxide and water are converted to sugars in green plants using energy from sunlight in the red and blue regions of the spectrum is the foundation of energy flow in the biosphere. Green plants make sugars. Animals eat plants and/or animals that eat plants.

The reaction without the complex details can be summarised as …

$$6CO_2 + 6H_2O + \text{Light Energy} = C_2H_{12}O_6 + 6O_2$$

… where $C_2H_{12}O_6$ is the formula for the simple sugars glucose and fructose.

Suppose solar cell efficiency is 20%. By that we mean 20% of the energy per square meter provided by sunlight is converted to electrical energy. How does that compare with energy conversion per square meter by a plant in our garden? To get an approximate answer to that question ourselves we can select a plant, collect some data and do some calculations.

We have a wild melon *Momordica cochinchinensis*. Now three years old, it covers an elevated frame: an area of about 25 m^2.

The solar constant

The solar constant is the energy delivered by sunlight, which is here typically close to 1000 joules per second per square meter at midday.

Estimates

The sun is high in the sky for around four hours a day, and lower for eight hours. There are often 3 to 4 hours of cloud cover at some time during the day. If we estimate the energy from available sunlight to be equivalent to five hours of bright mid-day sunshine, the energy delivered to the melon plant per month is …

$$5 \times 25 \times 1000 \times 60 \times 60 \times 30 = 13\,500 \text{ MJ}$$

Suppose we collect all the melons, and the leaves and stems that grow in a month, dry melon chips and green matter to make hay, and burn it. How much heat energy would be available from that?

The plant produces about 20, dense half-kg melons (like a cantaloup) per month, and a similar weight of stems and leaves. Melon stems grow 30 cm a day (10 metres a month) and are cut back almost weekly. Cantaloup is 90% water. Leaves and stems are similar to grass at 80% water. Hay for burning must be dried to about 15% water[1].

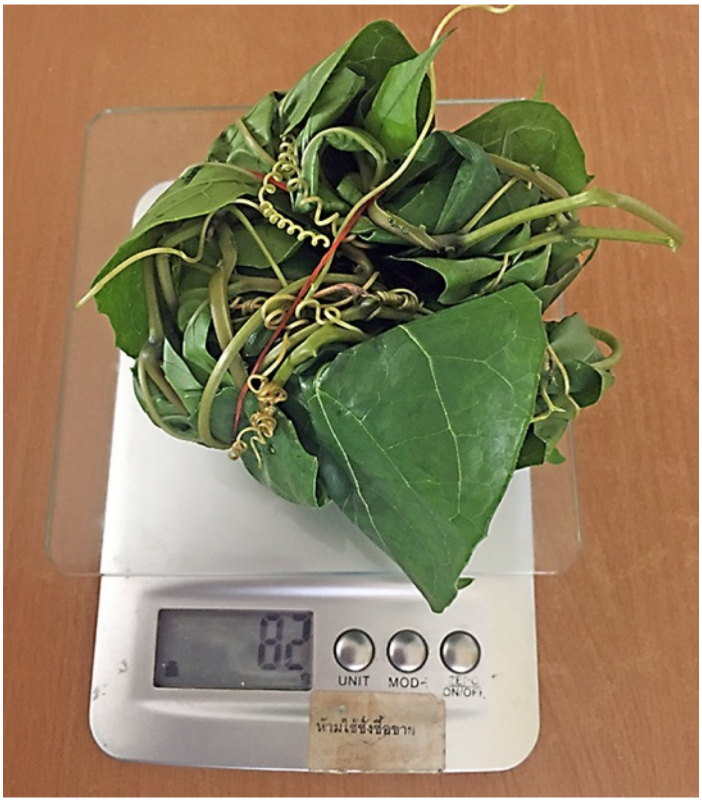
Taking these figures into account if we air-dry melon chips, stems and leaves to make hay, the weight of hay will be about 20% of the original weight, which gives 4 kg of hay per month. This figure is approximate and may be a little high, but we have neglected trunk and root growth per month.

The heat energy from burning hay is quoted by Caslin and Finnian[1] to be 14 MJ/kg. Using this figure, the energy from the sun per month to our melon is equivalent to burning 1000 kg (one ton) of hay. The solar energy conversion efficiency to hay is (4/1000)x100 = 0.4%.

[1] https://www.teagasc.ie/media/website/publications/2010/868_StrawForEnergy-1.pdf

Appendix

A two metre length of newly grown stem and leaves has a mass of around 80 grams.



Each stem grows about a metre a week, four metres a month. The plant has about 30 growing stems at any one time that are regularly cut back and new ones grow.

The mass of green matter produced per month is …

$$30 \times 4 \times 0.08 = \sim 10 \text{ kg}$$

The estimate is approximate. A more accurate figure could be found by weighing melon chips and stems cut weekly, sun drying it all on racks, and the hay from a month of clippings could be weighed. To measure the joules per kilogram available from burning the hay we could improvise a "bomb calorimeter", burn it under controlled conditions and measure the consequent temperature rise of a given mass of water. All this is possible, involves a lot of work, and would make a nice project for an IB extended essay some time in the future.

The melons are all of similar size.

The mass is a little more than half a kilogram.

The flesh of the red ripe melon is strongly flavoured. It makes a good contribution when added with other selected vegetables and large shrimp to an orange curry called *gaeng som*. We prefer to cook and eat them when they are slightly smaller and green, just before they turn yellow, so the average weight of melons picked from this plant is 500 grams.

The estimated efficiency of our melon as an energy converter is very low when compared to solar panels. It is a vigorous plant, a perennial that requires no insecticide or maintenance apart from regular pruning. We grow it for these reasons, not because of selection for high yield. This wild jungle species has not been bred as a commercial crop. Given that, we expect the efficiency of commercial energy crops to be more than our estimate of 0.4%.

Sugar cane is grown in Thailand for sugar and ethanol production.

For comparison, large scale sugar production in Brazil is reported to have an energy conversion efficiency of 0.38%[2]. Sugar (sucrose) has about 30% of the chemical energy stored in the canes at harvest. The remaining 70% is in the leaves and stems. If all these figures are reliable, the efficiency of sugar cane (a grass) is three times the efficiency of our melon, which is not unexpected.

As additional confirmation that our estimate of melon production efficiency is reasonable, the same article states that most crop plants store ~0.25% to 0.5% of the sunlight they receive in a product like corn or potatoes, and an estimate of the efficiency of biodiesel production from palm oil in Hawaii is 0.3%.

> Note: producing alcohol from sugar cane requires a factory and several steps. We do this because we want fuel to put in road vehicles. When all road transport becomes electric (which it will eventually) suppose we grow cane, make hay, and burn that to boil water in a steam-driven power plant. We do that now with bagasse (crushed cane waste). The energy equivalent of the hay with sugar would be ~20 MJ per kg. Would this be a cheaper way to convert energy? What might be the downsides of doing this?

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[2] https://en.wikipedia.org/wiki Photosynthetic_efficiency#Efficiencies_of_various_biofuel_crops