# A Food Energy

To introduce Food Energy, I ask the students to work through a few questions: at-the-buffet.jpg

## A.1 Converting food into body heat

Planning to save money, one college student decides to go to an all-you-can-eat buffet each day at 11am, eg figure **??**. If he brings homework and stretches the meal out for a few hours he can get all 3000*kcals* with only one bill. Food is fuel for the human body – could too much fuel make his body feel sick? If his body burned all this food at once, how much warmer would he get? Useful information: the student has a mass of 80*kg* and is made mostly of water. A Calorie heats 1*kg* of water 1◦*C*.

Here’s a possible answer: equate food energy with calorimetric heating and assume human bodies have the same heat capacity as water, about 1A black background with a black square

Description automatically generated with medium confidence. This allows us to calculate the body’s temperature increase.

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(10)

Students are normally quite surprised at this number. Although wildly unrealistic, ∆*T* ≈ +6◦*C* is typically fatal, there is a related phenomena of diet-induced thermogenesis, [6] known informally as “the meat sweats”. Some students connect this calculation to feeling quite hungry after a cold swim in the pool (a similar effect). On a larger scale, discussing what’s wrong with this estimate is useful. The main storage mechanism for storing food energy is fat tissue, which the calculation completely ignores. Infants are generally born with little fat, and an infant sleeping through the night often coincides with the baby developing enough fat tissue to store sufficient kcals to make it though a night without waking up ravenously hungry. A related follow-up is that if a person is stranded in the wilderness, they should immediately start walking downstream (ie, towards civilization) as they likely won’t be able to harvest an amount of kcals equivalent to what they already have stored on their hips and abdomen. [33] The contrast of bear hibernation, [27], and songbirds constantly eating through the winter are related connections to investigate.

## A.2 Biophysical Power

A more realistic question to follow up with relates to the average *power* given off by a person over a day. Again, assuming 3000*kcal* is burned over 24*hours*, with useful information: 1*kcal* ≈ 4200*J* and 1*J/s* = 1*W*.

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Description automatically generated with medium confidence (11)

Most students still remember 75*Watt* lightbulbs, but given the spread of LED lighting, “A person’s body heat is two 75*W* light bulbs” will probably only make sense for a few more years. Desert or cold-weather camping, alone versus with friends, and survival swimming are also examples for students to make sense of this answer. If you can take advantage of other people’s waste body heat, you’ll sleep more pleasantly and survive longer in cold water.

Another application to discuss is that of “brown fat,” a sort of biological space heater that humans and other mammals develop in response to cold weather. This tissue’s mitochondria can burn lipids and carbohydrates in a useless proton pumping scheme, which produces metabolic heat. [7, 11, 21, 31] Most common in rodents and infants, this mechanism can be stimulated by extended exposure to cold temperatures – the original work was done on lumberjacks in Finland. [22] The idea of a biological space heater that takes a month to turn on and a month to turn off matches the lived experience of college students in Minnesota, who wear down jackets in 4◦*C* weather in November, and beachwear in the same 4◦*C* weather in March. Additionally, transplants to northern climates often take a few years to “get used to” the colder weather up north. It seems just as easy to say that transplants’ bodies take a few years to develop the brown fat cells which allow them to be comfortable in cold weather.

One other distinction to emphasize is the difference between power and energy. A graph of a human body’s “kcal content” over the course of a day can be a useful illustration. When sedentary, this graph probably has the slope of

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Description automatically generated with medium confidence. If the 3000*kcal* meal at the buffet takes an hour, this

period corresponds to an energy-time slope of +3000A black background with a black square

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In medicine, these slopes known as “Metabolic Equivalent of Task” (METS), a common measure in cardiology and exercise physiology. METS is power normalized by mass, 1A black background with a black square

Description automatically generated with medium confidence, and METS levels are available for many different physical activities. [**?**] For example, doing the dishes is 2*.*1*METS*, folkdancing is 4*.*8*METS*, and the fun part of human reproduction reportedly ranks at 5*.*8*METS*. [19]

## A.3 Burning off food energy

Imagine that after eating a 600*kcal* bacon-maple long-john (donut), you decide to go for a hike to “work off” the Calories. Winona State is in a river valley bounded by 200*m* tall bluffs. How high up the bluff would you have to hike to burn off the donut? Useful information: human muscle is about 1*/*3 efficient, and on Earth’s surface, gravitational energy has a slope of about 10A black background with a black square

Description automatically generated with medium confidence. bar-chart.png

One way to approach this problem is by using Energy Bar Charts [4] to illustrate how the energy held in food changes form as it is used. An approximation for this question is shown in figure **??**. In this story, the “system” is taken to be the earth, food, and hiker. The hiker’s body is assumed to be 1*/*3 efficient, which means one of the food energy blocks of energy is transformed into gravitational energy (elevation) at the end of the hike. The other 2 blocks of energy are transformed into heat and leave the hiker’s body, most likely by mechanisms of respiration and sweat evaporation. The purpose of a bar chart like this is to provide a pictorial and mathematical representation of the energy conservation equation given in 12.

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Description automatically generated with medium confidence(12)

(13)

This estimate is again surprising to students. Five trips up the bluff to burn off $2 of saturated fat, sugar, and flour! A nice followup calculation is to imagine a car that can burn a 100*kcal* piece of toast in the engine: from rest, what speed will the toast propel it to? If (again) the engine converts 1*/*3 of the energy into motion (kinetic energy), a 1300*kg* Honda Civic will reach a speed of about

!

The point of these energy calculations is not to give students an eating disorder. Rather, the numbers show food’s amazing power. A single slice of toast will bring a car up to the residential speed limit! A day’s food, 3000*kcal*, will power you up an 5000*m* mountain peak! The body-work food allows us to do is astonishing, and increases in food production have made modern comforts, unimaginable 150 years ago, possible to the point of being taken for granted.

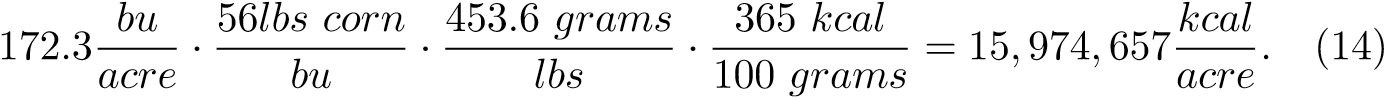
|  |  |
| --- | --- |
| Table 1: A summary of units and conversions used to create figure **??** from USDA NASS data. 1*cwt* is a hundred pounds of potatoes. A bushel, 1*bu*, is a volume unit of about 35liters and corresponds to about 60lbs of grain. Calorie content per 100 gram (mass) of food is taken from the USDA’s “Food Data Central” database. For context, typical serving sizes are included. It isn’t clear from any of these resources if lb is pound-force (lbf) or pound-mass (lbm) and so I am treating them as “grocery store units” where 1*lbs* ≈ 453*.*6*grams*. |  |
| Crop per acre unit production unit kcals per 100gram typical portion | FDC ID |
| Corn bu/acre 1*bu* = 56*lbs* 365 1 cup is 166g | 170288 |
| Potatoes cwt/acre 1*CWT* = 100*lbs* 77 0.5 cup is 75g | 170026 |
| Soybeans bu/acre 1*bu* = 60*lbs* 446 1 cup is 186g | 174270 |
| Sunflowers lbs/acre 584 1 cup is 140g | 170562 |
| Wheat bu/acre 1*bu* = 60*lbs* 327 1 cup is 192g | 168890 |

# B Creating the historical kcal/acre figure from USDA data

The United States Department of Agriculture (USDA) provides historical crop information via the National Agricultureal Statistics Service.[35] Data was downloaded in spreadsheet csv format and then combined and plotted via a Python Jupyter notebook.

Each crop has its own custom units, for example potatoes are sold by hundredweight (CWT) but sugar beets are measured by the ton. Every imaginable agricultural product seems to be tracked in the NASS site, for example Maple Syrup production is tracked and given in gallons of syrup per tap! Conversion factors used are summarized in Table 1. Calorie (kcal) density for each crop was taken from the USDA’s Food Data Central.[34] Within this database, foods are identified by an FDC ID.

An example calculation (implemented in the Jupyter notebook) follows for Corn. In 2022 the USDA reported an average production of 172*.*3 bushels of corn per acre of farmland.



Obviously the result is only reasonable to two significant figures!

Raw data from the USDA NASS is plotted in figure **??**. The scaling described in equation 14 produces figure **??** earlier in the paper. raw-production-peracre.pdf

# C Estimating land area devoted to chinampas with ImageJ

ImageJ is a free software program developed by the National Institutes of Health for photo analysis.[30] I used the program to measure a calibration scale in a map and I also used the program to measure the area of two polygons that I drew on the map. The length and both areas are shown in figure **??**.

Specifically, to find the area of the two large chinampas areas near Tenochtitlan, I took a screenshot from the 1964 paper,[9] and saved it in jpg format. Then, I opened the image in the Windows-Java edition of ImageJ.[30] The length of the 10 mile distance scale was 213 pixels. The long chinampas area at the south end of the lake was measured with a Polygon selection via the Measure tool to have an area of 9940 *pixel*2 ≈ 21*.*9*miles*2. The smaller region near Chalco had an area of about 1439 *pixel*2 ≈ 3*.*2*miles*2. While there were certainly other regions devoted to chimanpas agriculture, the portion visible near the Aztec capital seems to be about 25*.*1*miles*2 or 16*,*000*acres*. imageJ-analysis.jpg