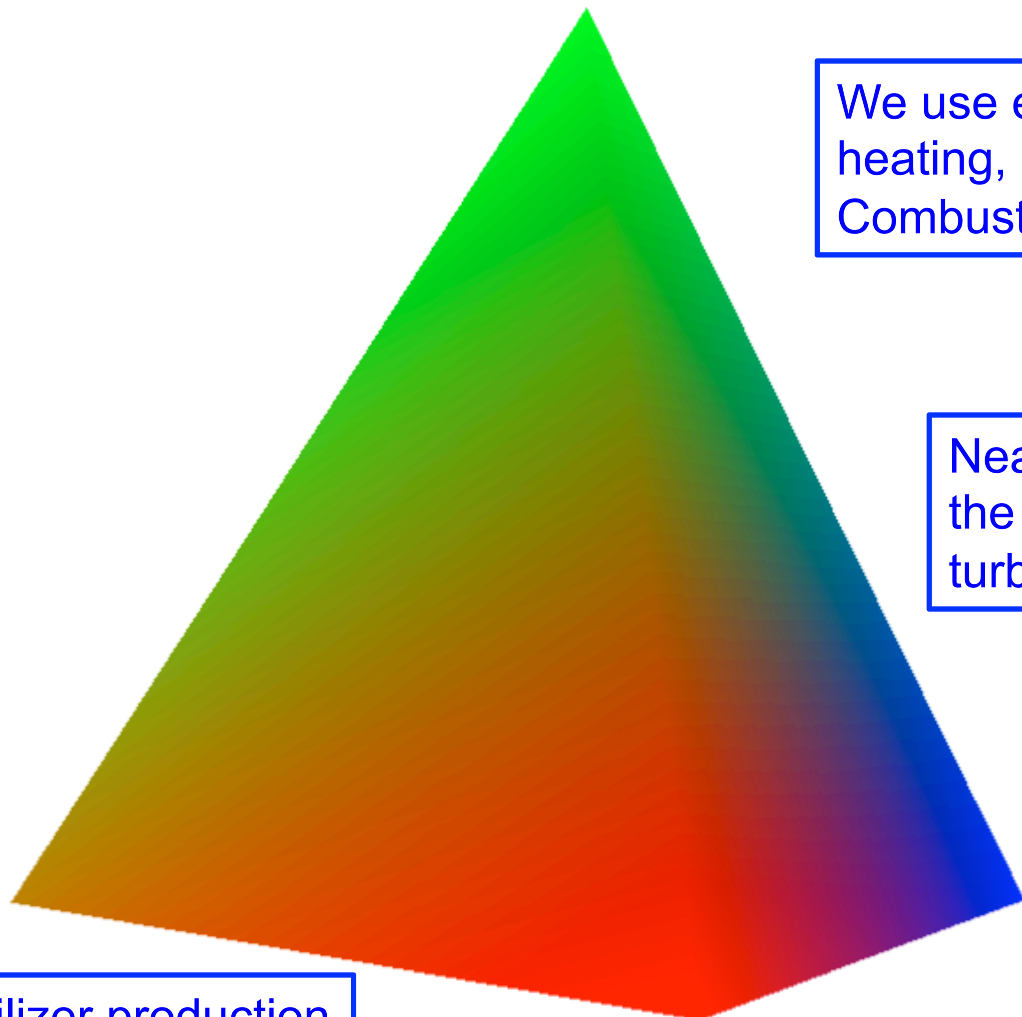
CHEM 103: Chemistry in Context

Unit 2

Energy, and its consequences

Interconnectedness of Issues: Energy



We use energy for transportation, heating, cooling, lights,…
Combustion leads to air, water pollution

Nearly 50% of the water that the US uses is for thermal turbine generation of electricity

Fertilizer production uses energy

Outline

What is Energy? | G&R Chapters 1-3 &
scale/magnitude | CC 4.1, 4.2

Where does energy come from? | G&R Chapter 4
Chemical equations, | CC 4.5-4.6, 1.9, 1.10, 2.2,2.3
energy from chemical transformations
stoichiometry

Combustion → air pollution → water pollution
→ greenhouse effect (global warming)

Energy, Work and Heat

Energy is the capacity to do work or supply heat

Work is done when movement occurs against a restraining force $W = F*d$

Power is work per unit time $P = W/t$

Heat is energy that flows from a hotter to a colder object
Temperature tells us the direction of heat flow

One joule (J) is the work done by a force of one Newton (N) acting through a distance of one meter $F = m*a$

One Newton is the force required to cause a mass of one kilogram to accelerate at a rate of one meter per second squared in the absence of other force-producing effects.

One calorie is roughly (it used to be exactly) the amount of heat needed to raise the temperature of one gram of water by 1 ˚C

1 calorie = 4.184 J
1000 calories = 1 Calorie

1 Calorie = 1kcal (a "food calorie")
1 kcal = 1.16 watt hr

Quantities

1 teaspoon of water ~ 5 grams (5 mL)
1 tablespoon ~15 mL
Average potato chip ~ 2-3 grams
2.2 lbs = 1 kg
1 ounce~28 grams

1 guart ~ 1L (1000 mL)
1000 mL water = 1000 grams (1 kg)

normal water bottle 1L & weighs 1 kg
2L soda bottle weighs 2 kg
8 fluid ounces a bit less that 250 mL

prefix	Power of 10
m	10^{-3}
c	10^{-2}
k	10^{3}

a dime ~ 1 mm thick
Your little finger ~ 1 cm wide
1 m a bit longer than 1 yard (3 feet) (39.37 inches)

Calories & Heat

One calorie is the amount of heat needed to raise the temperature of one gram of water by 1 ˚C

One Calorie (1000 calories, 1 kcal) is the amount of heat needed to raise the temperature of 1000 g (1 L) of water by 1 ˚C.

Heating a tea kettle of water from room temperature (25 ˚C) to boiling (100 ˚C), a temperature change of 75 ˚C, takes 75 Calories of energy.

Outside of nutrition we'll use the SI unit of energy, the Joule
1 calore=4.184 Joules

Energy/Heat cont.

a 2 ounce Snickers bar has 280 Calories

$$280 \text{ Calories} \times \frac{4.184 \text{ kJ}}{1 \text{ Calorie}} = 1172 \text{ kJ} \sim 1200 \text{ kJ}$$

Average daily nutritional need of a human is ~2400 Calories

8 Snickers bars

33 kettles of water brought to boiling

Table 11.8 Energy Expenditure for Common Physical Activities*

Moderate Physical Activity	Cal/hr	Vigorous Physical Activity	Cal/hr
hiking	370	jogging (5 mph)	590
light gardening/yard work	330	heavy yard work (chopping wood)	440
dancing	330	swimming (freestyle laps)	510
golf (walking, carrying clubs)	330	aerobics	480
bicycling (<10 mph)	290	bicycling (>10 mph)	590
walking (3.5 mph)	280	walking (4.5 mph)	460
weight lifting (light workout)	220	weightlifting (vigorous workout)	440
stretching	180	basketball (vigorous)	440

* Values include both resting metabolic rate and activity expenditure for a 70-kg (154-pound) person. Calories burned per hour are higher for persons heavier than 154 pounds and lower for persons who weigh less.

1 calore=4.184 Joules

1 Calorie=4.184 kJ

1 kcal=4.174 kJ

Energy density

2 ounce Snickers=1200 kJ

The energy density of a Snickers Bar is:

$$\frac{1200\text{kJ}}{2\text{ ounces}} \times \frac{1\text{ ounce}}{28\text{ grams}} = 21\text{ kJ/g}$$

unit conversion

Energy densities determined by combusting (burning) subtances & measuring the amount of heat given off (the impact on the temperature of water)

TABLE 2.1 — ENERGY DENSITY OF VARIOUS SUBSTANCES

SUBSTANCE	ENERGY DENSITY (kJ/g)
Hydrogen	141.9
Natural Gas (Methane)	55.8
Propane	50.4
Gasoline	46.5
Diesel	45.8
Vegetable Oil	39.6
Coal (Anthracite/Bituminous)	32
Ethanol	29.7
Coal (Sub-bituminous)	24
Sucrose (Table Sugar)	17
Wood	14.9

Snickers Bars equivalents

Vegetable Oil:

$$1200\,\text{kJ} \times \underbrace{\frac{1\,\text{g}}{39.6\,\text{kJ}}}_{\text{energy density}} \times \underbrace{\frac{1\,\text{mL}}{0.92\,\text{g}}}_{\text{density}} \times \underbrace{\frac{1\,\text{Tbsp}}{15\,\text{mL}}}_{\text{unit conversion}} = 2.2\,\text{Tbsp}$$

Table Sugar:

$$1200\,\text{kJ} \times \underbrace{\frac{1\,\text{g}}{17\,\text{kJ}}}_{\text{energy density}} \times \underbrace{\frac{1\,\text{tsp}}{4\,\text{g}}}_{\text{density}} = 18\,\text{tsp}\ (6\,\text{Tbsp})$$

(9 spoons of sugar in a 12 oz Coca-Cola)

Alcohol (190 Proof Vodka or Everclear):

$$1200\,\text{kJ} \times \underbrace{\frac{1\,\text{g}}{29.7\,\text{kJ}}}_{\text{energy density}} \times \underbrace{\frac{1\,\text{mL}}{0.79\,\text{g}}}_{\text{density}} = 51\,\text{mL}$$

(1 bit more than a 1.5 oz shot)

Gasoline:

$$1200\,\text{kJ} \times \underbrace{\frac{1\,\text{g}}{46.5\,\text{kJ}}}_{\text{energy density}} \times \underbrace{\frac{1\,\text{mL}}{0.72\,\text{g}}}_{\text{density}} = 36\,\text{mL}$$

Paper:

$$1200\,\text{kJ} \times \underbrace{\frac{1\,\text{g}}{17\,\text{kJ}}}_{\text{energy density}} \times \frac{1\,\text{piece of paper}}{4.5\,\text{g}} = 16\,\text{pieces of paper}$$

Electricity

100 Watt light bulb

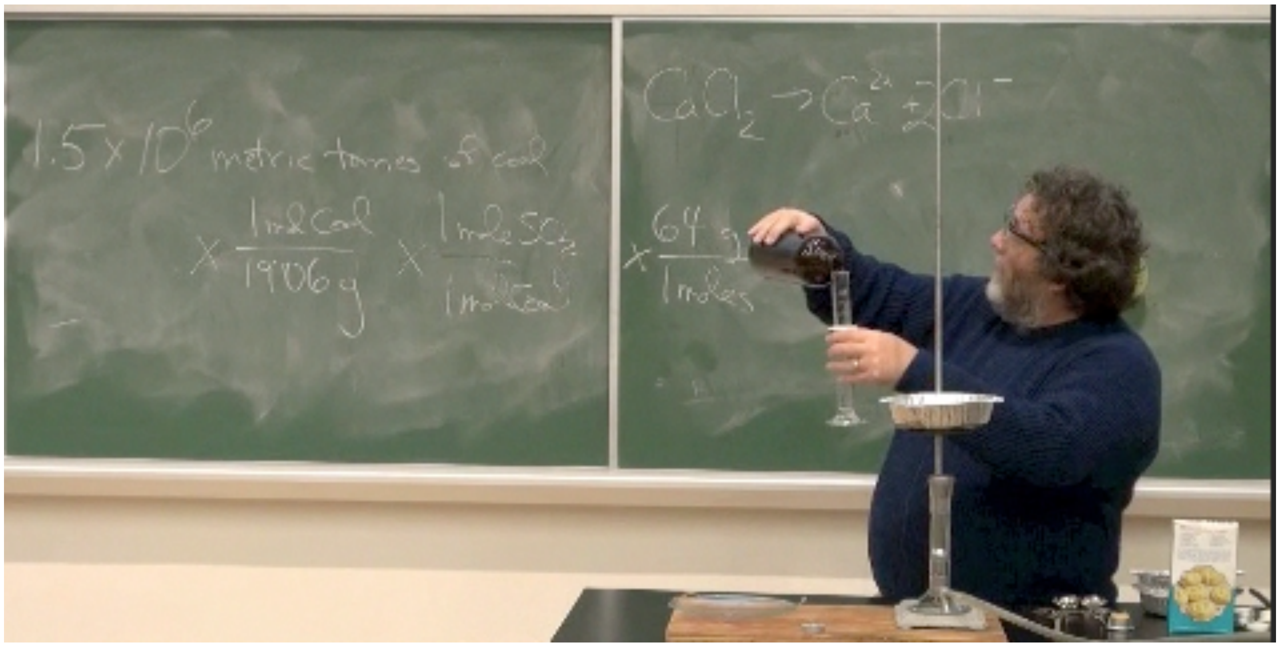
Electricity given in kilowatt-hours (kWh)
Watt a unit of Power (Energy/time)
W=1 Joule/second

$$1\text{ kWh} = \frac{1\text{ kJ}}{\text{s}} \times \frac{3600\text{ s}}{1\text{ hr}} \times 1\text{ hr} = 3600\text{ kJ}$$

$$1200\text{kJ} \times \frac{1\text{ kWh}}{3600\text{ kJ}} \times \frac{1000\text{ Wh}}{\text{kWh}} \times \frac{1}{100\text{ W}} = 3.33\text{ hrs}$$

Having a 100 Watt light bulb on for 3 1/3 hrs uses the same amount of energy as a Snickers bar

Combustion



Combustion of ethanol, sugar, paper, vegetable oil, and hydrogen gas

http://franklin.chem.colostate.edu/chem103/2013/l5/combustion.html

Daily Caloric need as unit of Energy

10,000 kJ is the average adult nutritional requirement per day

8.3 Snickers bars
18 tablespoons of vegetable oil
150 teaspoons of sugar
17 cans of Coke
9 shots of Everclear
133 pieces of paper
192 gallon-sized hydrogen ballons

A log of wood (50 cm x 20 cm (2.54 cm=1 in) (volume=15,700 cm^3)

$$15{,}700\ cm^3 \times \frac{0.6\ g}{cm^3} \times \frac{14.9\ kJ}{g} = 140{,}000\ kJ$$

14 days of food
117 Snicker bars

Tank of gas

$$15\ gallons \times \frac{3{,}785\ mL}{1\ gal} \times \frac{0.72\ g}{mL} \times \frac{46.5\ kJ}{g} = 1{,}900{,}000\ kJ$$

190 days of food
1600 Snicker bars

Tank of biodiesel

$$15\ gallons \times \frac{3{,}785\ mL}{1\ gal} \times \frac{0.92\ g}{mL} \times \frac{39.6\ kJ}{g} = 2{,}070{,}000\ kJ$$

207 days of food

Scaling Up

Heating your house in the winter
with natural gas ~110 Therms

1 Therm=100,000 Btu
1 Btu= 1.055 kJ

$$110\text{ Therms}\times\frac{100{,}000\text{ Btus}}{1\text{ Therm}}\times\frac{1.055\text{ kJ}}{\text{Btu}}=11{,}600{,}000\text{ kJ}=11.6\text{ GJ}$$

~ 6 tanks of gas or 3 years of food

Cooling your house in the summer

Typical central air conditioning unit draws 3800 Watts
If it runs for 12 hours a day you use 45,600 Wh (45.6 kWh)

$$45.6\text{ kWh}\times\frac{3{,}600\text{ kJ}}{1\text{ kWh}}\times 30\text{ days}=4{,}900{,}000\text{ kJ}=4.9\text{ GJ}$$

natural gas conversion to electricity is only
1/3 efficient so need to multiply by ~3 or 14.8 GJ

Energy in a coal train

coal car holds 120,000 kg of coal, coal train has 120 cars
Energy denisty of coal is 24 kJ/g

$$\frac{120{,}000\text{ kg coal}}{\text{car}}\times\frac{1000\text{ g}}{\text{kg}}\times\frac{24\text{ kJ}}{\text{g}}\times\frac{1000\text{ J}}{\text{kJ}}=\frac{2{,}900{,}000{,}000{,}000\text{ J}}{\text{car}}=2.9\times10^{12}\text{ J/car}=2.9\text{ TJ/car}$$

$$1\text{ train}\times\frac{120\text{ cars}}{\text{train}}\times\frac{2.9\text{ TJ}}{\text{car}}=346\text{ TJ}$$

Scaling Down (batteries)

Batteries are described in terms of Voltage & amp-hours
Volts x amp-hours = Watt-hours

12V lead acid battery rated at 70 amp-hours= 840 Wh=3,024 kJ

AA alkaline battery has 2.122 amp-hours=2.6 Wh= 9 kJ

Energy Scale

ENERGY		ENERGY SOURCE OR USE
9 kJ	10^4	1.225V Alkaline AA Battery
310 kJ	10^5	Heating a quart (Liter) of water
1.2 MJ	10^6	Snickers bar (2.2 Tbsp oil, 18 tsp sugar, 16 pieces of paper, a shot of alcohol)
3 MJ	10^6	12V lead acid battery
10 MJ	10^7	Nutritional energy required by one person per day
140 MJ	10^8	Burning a log of wood
2 GJ	10^9	Energy in 15 gallons of gasoline
11.6 GJ	10^{10}	Energy to heat your house in Colorado in January
100 GJ	10^{11}	Annual heating and electric use for a typical northern US home
2.9 TJ	10^{12}	Energy in a coal train car full of coal
346 TJ	10^{14}	Energy in a coal train full of coal (120 cars)

prefix	Power of 10
m	10^{-3}
c	10^{-2}
k	10^3
M	10^6
G	10^9
T	10^{12}
P	10^{15}
E	10^{18}