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ENVS 119 - Energy & the Environment
02 - Energy Def., Laws and Units

Today

- Energy Definition
- Laws of thermodynamics
- Energy efficiency
- Calculations
- Group practice
- Wrap-up

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Energy Definition, Laws of Thermodynamics

Energy: “The capacity to do work” or “Energy allows us to make things get hotter, move faster, go uphill…

1st Law of Thermodynamics: Energy is neither created or destroyed, it moves or changes form when stored, converted, or used.

2nd Law of Thermodynamics: Every time we do something with energy there is always some loss in energy quality or higher entropy.

What are the different forms of energy?

- Electro-magnetic/solar (*r*): magnets, light…
- Chemical (*c*): Gasoline, coal, natural gas, wood…
- Thermal (*t*): Warm elements can transfer heat to something else
- Kinetic/Mechanical (*m*): An object in motion can transfer its energy
- Electric (*e*): Electricity (electrons moving among molecules).
- Nuclear: Extremely powerful forces that hold a nucleus together.
- Gravitational: Gravity, pressure,…

The ratio between energy input and useful output is
<u>the efficiency</u> of the system.

Example of Energy Conversions & Efficiencies

Conversions	Energies	Efficiencies
Large electricity generators	M → e	98–99
Large power-plant boilers	c → t	90–98
Large electric motors	e → m	90–97
Best home natural-gas furnaces	c → t	90–96
Dry-cell batteries	c → e	85–95
Human lactation	c → c	85–95
Overshot waterwheels	m → m	60–85
Small electric motors	e → m	60–75
Large steam turbines	t → m	40–45
Improved wood stoves	c → t	25–45
Large gas turbines	c → m	35–40
Diesel engines	c → m	30–35
Mammalian postnatal growth	c → c	30–35
Best photovoltaic cells	r → e	20–30

Diesel engines	c → m	30–35
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Best large steam engines	c → m	20–25
Internal combustion engines	c → m	15–25
High-pressure sodium lamps	e → r	15–20
Mammalian muscles	c → m	15–20
Traditional stoves	c → t	10–15
Fluorescent lights	e → r	10–12
Steam locomotives	c → m	3–6
Peak crop photosynthesis	r → c	4–5
Incandescent light bulbs	e → r	2–5
Paraffin candles	c → r	1–2
Most productive ecosystems	r → c	1–2
Global photosynthetic mean	r → c	0.3

Energy labels: c — chemical, e — electrical, m — mechanical (kinetic), r — radiant (electromagnetic, solar), t — thermal

Energy Units are Form Dependent

Source	Energy content	Quantity
Natural gas	Therms/Btu/Joules	Cf/Ft^3
Petroleum	Joules/ Btu	Gallons/Quads
Coal	Joules/Btu	Tons
Electricity	Wh/Btu/Joules	?

Power v. Energy unit

- **Power**: (constant) rate flow of energy
- **Energy unit**: How much power is used over a define amount of time

Power	Energy Units
Watt (w) Always ON	Watt hour (wh)
kW	kWh
Horse power (hp)	0.7068 Btu/s

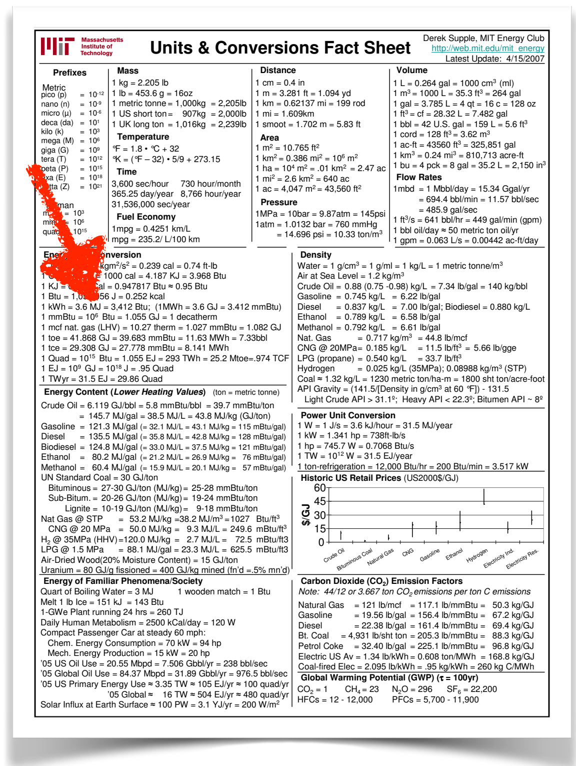
Energy Calculation Principles

- **From the MIT Units and Conversion Fact Sheet:**

$$1\ \text{kWh} = 3{,}412\ \text{Btu} \quad \textbf{or} \quad \frac{1\ \text{kWh}}{3{,}412\ \text{Btu}} = \frac{3{,}412\ \text{Btu}}{1\ \text{kWh}} = 1$$

- **Convert 100 kWh in Btu?**

$$100\ \cancel{\text{kWh}} \times \frac{3{,}412\ \text{Btu}}{1\ \cancel{\text{kWh}}} = 341{,}200\ \text{Btu}$$


Massachusetts Institute of Technology
Units & Conversions Fact Sheet
Derek Supple, MIT Energy Club
http://web.mit.edu/mit_energy
Latest Update: 4/15/2007

Prefixes
Metric
pico (p) = 10^{-12}
nano (n) = 10^{-9}
micro (μ) = 10^{-6}
deca (da) = 10^{1}
kilo (k) = 10^{3}
mega (M) = 10^{6}
giga (G) = 10^{9}
tera (T) = 10^{12}
peta (P) = 10^{15}
exa (E) = 10^{18}
zetta (Z) = 10^{21}
man
m = 10^{3}
mm = 10^{6}
quad = 10^{15}

Mass
1 kg = 2.205 lb
1 lb = 453.6 g = 16oz
1 metric tonne = 1,000kg = 2,205lb
1 US short ton = 907kg = 2,000lb
1 UK long ton = 1,016kg = 2,239lb

Temperature
°F = 1.8 • °C + 32
°K = (°F – 32) • 5/9 + 273.15

Time
3,600 sec/hour 730 hour/month
365.25 day/year 8,766 hour/year
31,536,000 sec/year

Fuel Economy
1mpg = 0.4251 km/L
mpg = 235.2/ L/100 km

Distance
1 cm = 0.4 in
1 m = 3.281 ft = 1.094 yd
1 km = 0.62137 mi = 199 rod
1 mi = 1.609km
1 smoot = 1.702 m = 5.83 ft

Area
1 m^2 = 10.765 ft^2
1 km^2 = 0.386 mi^2 = 10^6 m^2
1 ha = 10^4 m^2 = .01 km^2 = 2.47 ac
1 mi^2 = 2.6 km^2 = 640 ac
1 ac = 4,047 m^2 = 43,560 ft^2

Pressure
1MPa = 10bar = 9.87atm = 145psi
1atm = 1.0132 bar = 760 mmHg
= 14.696 psi = 10.33 ton/m^3

Volume
1 L = 0.264 gal = 1000 cm^3 (ml)
1 m^3 = 1000 L = 35.3 ft^3 = 264 gal
1 gal = 3.785 L = 4 qt = 16 c = 128 oz
1 ft^3 = cf = 28.32 L = 7.482 gal
1 bbl = 42 U.S. gal = 159 L = 5.6 ft^3
1 cord = 128 ft^3 = 3.62 m^3
1 ac-ft = 43560 ft^3 = 325,851 gal
1 km^3 = 0.24 mi^3 = 810,713 acre-ft
1 bu = 4 pck = 8 gal = 35.2 L = 2,150 in^3

Flow Rates
1mbd = 1 Mbbl/day = 15.34 Ggal/yr
= 694.4 bbl/min = 11.57 bbl/sec
= 485.9 gal/sec
1 ft^3/s = 641 bbl/hr = 449 gal/min (gpm)
1 bbl oil/day ≈ 50 metric ton oil/yr
1 gpm = 0.063 L/s = 0.00442 ac-ft/day

Ene... onversion
... kgm^2/s^2 = 0.239 cal = 0.74 ft-lb
1 ... = 1000 cal = 4.187 KJ = 3.968 Btu
1 KJ = ... al = 0.947817 Btu ≈ 0.95 Btu
1 Btu = 1,0...56 J = 0.252 kcal
1 kWh = 3.6 MJ = 3,412 Btu; (1MWh = 3.6 GJ = 3.412 mmBtu)
1 mmBtu = 10^6 Btu = 1.055 GJ = 1 decatherm
1 mcf nat. gas (LHV) = 10.27 therm = 1.027 mmBtu = 1.082 GJ
1 toe = 41.868 GJ = 39.683 mmBtu = 11.63 MWh = 7.33bbl
1 tce = 29.308 GJ = 27.778 mmBtu = 8.141 MWh
1 Quad = 10^{15} Btu = 1.055 EJ = 293 TWh = 25.2 Mtoe=.974 TCF
1 EJ = 10^9 GJ = 10^{18} J = .95 Quad
1 TWyr = 31.5 EJ = 29.86 Quad

Energy Content (*Lower Heating Values*) (ton = metric tonne)
Crude Oil = 6.119 GJ/bbl = 5.8 mmBtu/bbl = 39.7 mmBtu/ton
= 145.7 MJ/gal = 38.5 MJ/L = 43.8 MJ/kg (GJ/ton)
Gasoline = 121.3 MJ/gal (= 32.1 MJ/L = 43.1 MJ/kg = 115 mBtu/gal)
Diesel = 135.5 MJ/gal (= 35.8 MJ/L = 42.8 MJ/kg = 128 mBtu/gal)
Biodiesel = 124.8 MJ/gal (= 33.0 MJ/L = 37.5 MJ/kg = 121 mBtu/gal)
Ethanol = 80.2 MJ/gal (= 21.2 MJ/L = 26.9 MJ/kg = 76 mBtu/gal)
Methanol = 60.4 MJ/gal (= 15.9 MJ/L = 20.1 MJ/kg = 57 mBtu/gal)
UN Standard Coal = 30 GJ/ton
Bituminous = 27-30 GJ/ton (MJ/kg) = 25-28 mmBtu/ton
Sub-Bitum. = 20-26 GJ/ton (MJ/kg) = 19-24 mmBtu/ton
Lignite = 10-19 GJ/ton (MJ/kg) = 9-18 mmBtu/ton
Nat Gas @ STP = 53.2 MJ/kg = 38.2 MJ/m^3 = 1027 Btu/ft^3
CNG @ 20 MPa = 50.0 MJ/kg = 9.3 MJ/L = 249.6 mBtu/ft^3
H_2 @ 35MPa (HHV) = 120.0 MJ/kg = 2.7 MJ/L = 72.5 mBtu/ft3
LPG @ 1.5 MPa = 88.1 MJ/gal = 23.3 MJ/L = 625.5 mBtu/ft3
Air-Dried Wood(20% Moisture Content) = 15 GJ/ton
Uranium = 80 GJ/g fissioned = 400 GJ/kg mined (fn'd =.5% mn'd)

Energy of Familiar Phenomena/Society
Quart of Boiling Water = 3 MJ 1 wooden match = 1 Btu
Melt 1 lb Ice = 151 kJ = 143 Btu
1-GWe Plant running 24 hrs = 260 TJ
Daily Human Metabolism = 2500 kCal/day = 120 W
Compact Passenger Car at steady 60 mph:
Chem. Energy Consumption = 70 kW = 94 hp
Mech. Energy Production = 15 kW = 20 hp
'05 US Oil Use = 20.55 Mbpd = 7.506 Gbbl/yr = 238 bbl/sec
'05 Global Oil Use = 84.37 Mbpd = 31.89 Gbbl/yr = 976.5 bbl/sec
'05 US Primary Energy Use ≈ 3.35 TW ≈ 105 EJ/yr ≈ 100 quad/yr
'05 Global ≈ 16 TW ≈ 504 EJ/yr ≈ 480 quad/yr
Solar Influx at Earth Surface ≈ 100 PW = 3.1 YJ/yr = 200 W/m^2

Density
Water = 1 g/cm^3 = 1 g/ml = 1 kg/L = 1 metric tonne/m^3
Air at Sea Level = 1.2 kg/m^3
Crude Oil = 0.88 (0.75 -0.98) kg/L = 7.34 lb/gal = 140 kg/bbl
Gasoline = 0.745 kg/L = 6.22 lb/gal
Diesel = 0.837 kg/L = 7.00 lb/gal; Biodiesel = 0.880 kg/L
Ethanol = 0.789 kg/L = 6.58 lb/gal
Methanol = 0.792 kg/L = 6.61 lb/gal
Nat. Gas = 0.717 kg/m^3 = 44.8 lb/mcf
CNG @ 20MPa = 0.185 kg/L = 11.5 lb/ft^3 = 5.66 lb/gge
LPG (propane) = 0.540 kg/L = 33.7 lb/ft^3
Hydrogen = 0.025 kg/L (35MPa); 0.08988 kg/m^3 (STP)
Coal ≈ 1.32 kg/L = 1230 metric ton/ha-m = 1800 sht ton/acre-foot
API Gravity = (141.5/[Density in g/cm^3 at 60 °F]) - 131.5
Light Crude API > 31.1º; Heavy API < 22.3º; Bitumen API ~ 8º

Power Unit Conversion
1 W = 1 J/s = 3.6 kJ/hour = 31.5 MJ/year
1 kW = 1.341 hp = 738ft-lb/s
1 hp = 745.7 W = 0.7068 Btu/s
1 TW = 10^{12} W = 31.5 EJ/year
1 ton-refrigeration = 12,000 Btu/hr = 200 Btu/min = 3.517 kW

Historic US Retail Prices (US2000$/GJ)

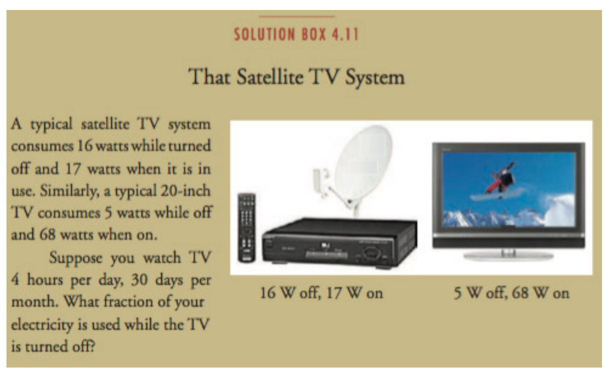
Carbon Dioxide (CO_2) Emission Factors
Note: 44/12 or 3.667 ton CO_2 emissions per ton C emissions
Natural Gas = 121 lb/mcf = 117.1 lb/mmBtu = 50.3 kg/GJ
Gasoline = 19.56 lb/gal = 156.4 lb/mmBtu = 67.2 kg/GJ
Diesel = 22.38 lb/gal = 161.4 lb/mmBtu = 69.4 kg/GJ
Bt. Coal = 4,931 lb/sht ton = 205.3 lb/mmBtu = 88.3 kg/GJ
Petrol Coke = 32.40 lb/gal = 225.1 lb/mmBtu = 96.8 kg/GJ
Electric US Av = 1.34 lb/kWh = 0.608 ton/MWh = 168.8 kg/GJ
Coal-fired Elec = 2.095 lb/kWh = .95 kg/kWh = 260 kg C/MWh

Global Warming Potential (GWP) (τ = 100yr)
CO_2 = 1 CH_4 = 23 N_2O = 296 SF_6 = 22,200
HFCs = 12 - 12,000 PFCs = 5,700 - 11,900

Example (power v. Electricity unit)

Satellite box power is 16W (Off) and 17W (On)
Flat screen TV is 5W (Off) and 68 W (On)

1. Calculate the electricity used in Wh if TV is used 4 hours a day during 1 month (31 days). What fraction of the total electricity used is really useful when TV is On?
2. If electricity is sold $0.17 kWh by PG&E what is the cost per month of the system in standby (20 hours Off)?


SOLUTION BOX 4.11

That Satellite TV System

A typical satellite TV system consumes 16 watts while turned off and 17 watts when it is in use. Similarly, a typical 20-inch TV consumes 5 watts while off and 68 watts when on.

Suppose you watch TV 4 hours per day, 30 days per month. What fraction of your electricity is used while the TV is turned off?

16 W off, 17 W on

5 W off, 68 W on

Group Work or Exercise

- Back to class
  (10 minutes before end of class time)
- Start with TV ON (68W) for 4 hours/day in 31 days period (1 month)

$$68\ \cancel{W} \times \frac{1\ kW}{1{,}000\ \cancel{W}} \times \frac{4\ h}{1\ \cancel{day}} \times \frac{31\ \cancel{days}}{1\ month} = \underline{kWh\ in\ 1\ month}$$

- Add: TV OFF (5W) for 20 hours/day in 1 month
- Add: Sat. Box OFF (16W) for 20 hours/day in 1 month
- Add: Sat. Box ON (17W) for 4 hours/day in 1 month

ENVS/ENGR 119 - Lecture 03

End