Energy in natural processes and human consumption - some numbers

The average person in the US consumes 60 barrels of oil (2520 gallons) per year and on average this is 10,000 watts of power consumption (the calculation is made relatively easy by consulting tables below and keeping track of units: [2520 gallons /yr x 125 x 10^6 J/gallon]/ [π x 10^7 sec./yr] = 1.00 x10^4 watts). It is a useful coincidence that the number of seconds in a year is π x 10^7 to within half of one percent.

Rough Values of Power of Various Processes (watts)

Solar power in all directions	10^{27}
Solar power incident on earth	10^{17}
Solar power avg. on U.S.	10^{15}
Solar power consumed in photosynthesis	10^{14}
U.S. power consumption rate	10^{13}
U.S. electrical power	10^{12}
Large electrical generating plant	10^9
Automobile at 40 mph…note this is not the output which only about 30% of the energy input..PBR	10^5
Solar power on roof of U.S. home	10^4
U.S. citizen consumption rate	10^4
Electric stove	10^4
Solar power per m^2 on U.S. surface …this seems a little low…it's 1342 watts per m^2 outside the atmosphere, about 1000 watts per m^2 at high noon on the ground, and on average (day and night) about 240 watts per meter^2 absorbed at the ground. This is the average over the Earth too…PBR	10^2
One light bulb	10^2
Food consumption rate per capita U.S.	10^2
Electric razor	10^1

Energy Content of Fuels (in Joules)

Energy Unit	**Joules Equivalent (S.I.)**

gallon of gasoline	1.3×10^8
AA battery	10^3
standard cubic foot of natural gas (SCF)	1.1×10^6
candy bar	10^6
barrel of crude oil (contains 42 gallons)	6.1×10^9
pound of coal	1.6×10^7
pound of gasoline	2.2×10^7
pound of oil	2.4×10^7
pound of Uranium-235	3.7×10^{13}
ton of coal	3.2×10^{10}
ton of Uranium-235	7.4×10^{16}

Energy Conversions

Energy Unit	Equivalent				
1 Btu	1055 joules	or	778 ftlb	or	252 cal
1 calorie	4.184 joules				
1 food Calorie	1000 calories	or	1 kilocalorie		
1 hp hr	2.68×10^6 joules	or	0.746 kwh		
1 kwh	3.6×10^6 joules	or	3413 Btu		
1 eV	1.6×10^{-19} joules				

Fuel Requirements for a 1000MWe Power Plant =10^9 watts

($2.4\ 10^{11}$ Btu/day energy input)

=2.53×10^{14} joules/day = 2.9×10^9 watts = 2200 Mwatts thermal fuel energy

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Coal: 9000 tons/day of 1 "unit train load" (100 90 - ton cars/day)

Oil: 40,000 bbl/day or 1 tanker per week (note: "bbl" means barrels)

Natural Gas: $2.4\ 10^8$ SCF/day

Uranium (as ^{235}U): 3 kg/day

Note: 1000 MWe utility, at 60% load factor, = 6 x 10^5 kw generates 5.3 x 10^9 kwh/year, enough for a city of about 1 million people in the U.S.A ; this is just their electricity needs, at about 0.6 kw per person

(Note: MWE is an abbreviation for megawatts-electrical output)

Global Energy Consumption

Global Energy consumption (marketable energy): about 400 exaJoules per year = 4 x 10^{20} J/yr

U.S. Total Energy Consumption (1990)

= 82.1$10^{15}$ Btu (82.1 Quads) = 38.8 MBPD oil equivalent = 86.6x10^9 GJ = 86.6 exaJoule;   (recall 1 Quad is a quadrillion (10^{15}) BTU or 1.055 exaJoules (1.055 x 10^{18} Joules). Since 1990 we've gone up.

Everyday Usage and Energy Equivalencies

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1 barrel of oil = 42 gallons: driving 1400 km (840 miles) in average car

1 kwh electricity = 1½ hours of operation of standard air conditioner

= 92 days for electric clock

= 24 hours for color TV

One million Btu equals approximately

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90 pounds of coal

125 pounds of ovendried wood

8 gallons of motor gasoline

10 therms of natural gas

1.1 day energy consumption per capita in the U.S.

Power is the amount of energy used per unit time - or how fast energy is being used. If we multiply a unit of power by a unit of time, the result is a unit of energy. Example: kilowatt-hour.

Power Conversions

Power Unit	Equivalent				
1 watt	1 joule/s	or	3.41 Btu/hr		
1 hp		or	2545 Btu/hr	or	746 watts

Power Converted to Watts

Quantity	Equivalent
1 Btu per hour	0.293 W
1 joule per second	1 W
1 kilowatt-hour per day	41.7 W
1 food Calorie per minute	69.77 W
1 horsepower	745.7 W
1 kilowatt	1000 W
1 Btu per second	1054 W
1 gallon of gasoline per hour	39 kW
1 million barrels of oil per day	73 GW

Rough Values of the Energies of Various Events

Occurrence	Energy (J)
Creation of the Universe	10^{68}
Emission from a radio galaxy	10^{55}
$E = mc^2$ of the Sun	10^{47}
Supernova explosion	10^{44}
Yearly solar emission	10^{34}
Earth moving in orbit	10^{33}

D-D fusion energy possible from worlds oceans	10^{31}
Earth spinning	10^{29}
Earth's annual sunshine	10^{25}
Cretaceous-Tertiary extinction theory meteorite	10^{23}
Energy available from earth's fossil fuels	10^{23}
Yearly U.S. sunshine	10^{23}
tidal friction (which drives the moon slowly away from Earth and lengthens the day steadily)	10^{20}
U.S. energy consumption	10^{20}
Exploding volcano (Krakatoa)	10^{19}
Severe earthquake (Richter 8)	10^{18}
100-megaton H-bomb	10^{17}
Fission one ton of Uranium	10^{17}
$E = mc^2$ of 1 kilogram	10^{17}
Burning a million tons of coal	10^{16}
Energy to create Meteor Crater in Arizona	10^{16}
1000-MW power station (1 year)	10^{16}
Hurricane	10^{15}
Thunderstorm	10^{15}
Atomic Bomb (Hiroshima)	10^{14}
$E = mc^2$ of 1 gram	10^{14}
Energy to put the space shuttle in orbit	10^{13}
Energy used in one year per capita U.S.	10^{12}
Atlantic crossing (one way) of jet airliner	10^{12}

Saturn V rocket	10^{11}
Energy to heat a house for one year	10^{11}
D-D fusion energy possible from 1 gal. of water	10^{11}
One year of electricity for the average house	10^{10}
Lightening bolt	10^{10}
Burning a cord of wood	10^{10}
One gallon of gasoline	10^{8}
100-W light bulb left on for one day	10^{7}
Human daily diet	10^{7}
One day of heavy manual labor	10^{7}
Explosion of 1 kg of TNT	10^{6}
Woman running for 1 hr	10^{6}
Candy bar	10^{6}
Burning match	10^{3}

1AA battery (alkaline)	10^3
Hard-hit baseball	10^3
Lifting an apple 1 m	1
Human heartbeat	0.5
Depressing typewriter key	10^{-2}
Cricket chirrup	10^{-3}
Hopping flea	10^{-7}
Proton accelerated to high energy (one trillion eV)	10^{-7}
Fission of 1 uranium nucleus	10^{-11}
Energy released in D-D fusion	10^{-12}
Electron mass-energy	10^{-13}
Chemical reaction per atom	10^{-18}
Photon of light	10^{-19}
Energy of room-temperature air molecule	10^{-21}

Cost of Various Fuels

Type	Unit	Cost $/Unit	Cost $/Joule	Uses
Electricity	1Kwh=$3.6x10^6$J (3.6 MJ)	$0.10	0.028 $/MJ = $2.8x10^{-8}$	appliances, motors
Gasoline	1 gallon	2.00	0.013 $/MJ = $1.3x10^{-8}$	transportation
Natural Gas	1 Therm	0.60	similar to gasoline	heating
AA battery	1 battery	0.80	0.8 x 10^{-3}	portable electronics
Milky Way candy bar	1 bar	0.60	0.60/MJ = 0.6 x 10^{-6}	food

(but note, although electricity is twice as expensive as gasoline per unit of energy, electric motors are typically much more efficient than gasoline engines, so that electricity as a fuel source can be competitive with gasoline).

Worldwide Power Use - History

"Developed" countries average (1990):

- 1.2 billion people 7.5 kilowatts/per person = 9.0 terawatts

The rest of the world (1990):

- 4.1 billion people 1.1 kilowatts/person = 4.5 terawatts

(*…we got a slightly different number for 2000…taking 400 exaJoules/year and dividing by 6 Billion people gave 2.11 kw per person..average power consumption..24 hrs a da*y!..has it changed? Here we used the interesting fact that there are $\pi \times 10^7$ seconds per year…to a good approx. PBR)

World Population (est.) (billion persons)	Year	Average Power Use (terawatts)
5.5	1990	13.5
3.6	1970	8.4
2.5	1959	3.2
2.0	1930	2.3
1.7	1910	1.6
1.5	1890	1

Areas and crop yields

- 1.0 hectare = 10,000 m^2 (an area 100 m x 100 m, or 328 x 328 ft) = 2.47 acres
- 1.0 km^2 = 100 hectares = 247 acres
- 1.0 acre = 0.405 hectares
- 1.0 US ton/acre = 2.24 t/ha
- 1 metric tonne/hectare = 0.446 ton/acre
- 100 g/m^2 = 1.0 tonne/hectare = 892 lb/acre
  - for example, a "target" bioenergy crop yield might be: 5.0 US tons/acre (10,000 lb/acre) = 11.2 tonnes/hectare (1120 g/m^2)

Biomass energy

- **Cord:** a stack of wood comprising 128 cubic feet (3.62 m^3); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approx. 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg
  - 1.0 metric tonne (that is, 1000 kg) **wood** = 1.4 cubic meters (solid wood, not stacked)
  - Energy content of **wood fuel** (HHV, bone dry) = 18-22 GJ/t = 18-22 MJ/kg (7,600-9,600 Btu/lb)
  - Energy content of **wood fuel** (air dry, 20% moisture) = about 15 GJ/t (or 15 MJ/kg) (or 6,400 Btu/lb)
- Energy content of **agricultural residues** (range due to moisture content) = 10-17 GJ/t (4,300-7,300 Btu/lb)
- Metric tonne **charcoal** = 30 GJ (= 12,800 Btu/lb) (but usually derived from 6-12 t air-dry wood, i.e. 90-180 GJ original energy content)
- Metric tonne **ethanol** = 7.94 petroleum barrels = 1262 liters

- ethanol energy content (LHV) = 11,500 Btu/lb = 75,700 Btu/gallon = 26.7 GJ/t = 21.1 MJ/liter. HHV for ethanol = 84,000 Btu/gallon = 89 MJ/gallon = 23.4 MJ/liter
- ethanol density (average) = 0.79 g/ml (= metric tonnes/m^3)

- Metric tonne **biodiesel** = 37.8 GJ (33.3 - 35.7 MJ/liter)
  - biodiesel density (average) = 0.88 g/ml (= metric tonnes/m^3)

Fossil fuels

- **Barrel of oil** equivalent (boe) = approx. 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. ***One "Petroleum barrel" is a liquid measure equal to 42 U.S. gallons*** (35 Imperial gallons or 159 liters); about 7.2 barrels oil are equivalent to one tonne of oil (metric) = 42-45 GJ.
- **Gasoline:** US gallon = 115,000 Btu = 121 MJ = 32 MJ/liter (LHV). 'Premium' or HHV gasoline = 125,000 Btu/gallon = **132 MJ/gallon** = 35 MJ/liter
  - Metric tonne gasoline = 8.53 barrels = 1356 liter = 43.5 GJ/t (LHV); 47.3 GJ/t (HHV)
  - gasoline density (average) = 0.73 g/ml (= metric tonnes/m^3)
- **Petro-diesel** = 130,500 Btu/gallon (36.4 MJ/liter or 42.8 GJ/t)
  - petro-diesel density (average) = 0.84 g/ml (= metric tonnes/m^3)
- Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.
- Metric tonne **coal** = 27-30 GJ (bituminous/anthracite); 15-19 GJ (lignite/sub-bituminous) (the above ranges are equivalent to 11,500-13,000 Btu/lb and 6,500-8,200 Btu/lb).
  - Note that the energy content (heating value) per unit mass varies greatly between different "ranks" of coal. "Typical" coal (rank not specified) usually means bituminous coal, the most common fuel for power plants (27 GJ/t).
- **Natural gas:** HHV = 1027 Btu/ft3 = 38.3 MJ/m^3; LHV = 930 Btu/ft3 = 34.6 MJ/m^3
  - Therm (used for natural gas, methane) = 100,000 Btu (= 105.5 MJ)

Carbon content of fossil fuels and bioenergy feedstocks

- **coal** (average) = 25.4 metric tonnes carbon per terajoule (TJ)
  - 1.0 metric tonne **coal** = 746 kg carbon
- **oil** (average) = 19.9 metric tonnes carbon / TJ
- 1.0 US gallon **gasoline** (0.833 Imperial gallon, 3.79 liter) = 2.42 kg carbon
- 1.0 US gallon **diesel/fuel oil** (0.833 Imperial gallon, 3.79 liter) = 2.77 kg carbon

- **natural gas (methane)** = 14.4 metric tonnes carbon / TJ
- 1.0 cubic meter **natural gas (methane)** = 0.49 kg carbon
- carbon content of **bioenergy feedstocks:** approx. 50% for woody crops or wood waste; approx. 45% for graminaceous (grass) crops or agricultural residues

GASOLINE:
Energy content: 43 to 47 KJ/gram (that is , 43 – 47 MJ/kg) not much different from candlewax or candybars
(physical density of gasoline is about .73 times that of water (.73 g/cc…it floats!).
Coal has energy content of 15 to 19 KJ/gram

Typical molecules found in gasoline

```
  H H H H H H H
  | | | | | | |
H-C-C-C-C-C-C-C-H         Heptane
  | | | | | | |
  H H H H H H H


  H H H H H H H H
  | | | | | | | |
H-C-C-C-C-C-C-C-C-H       Octane
  | | | | | | | |
  H H H H H H H H


  H H H H H H H H H
  | | | | | | | | |
H-C-C-C-C-C-C-C-C-C-H     Nonane
  | | | | | | | | |
  H H H H H H H H H


  H H H H H H H H H H
  | | | | | | | | | |
H-C-C-C-C-C-C-C-C-C-C-H   Decane
  | | | | | | | | | |
  H H H H H H H H H H
```

compare with 'cleaner' natural gas: methane, which has roughly ½ carbon:hydrogen ratio of gasoline

```
  H
  |
H-C-H   Methane  CH4
  |
  H
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