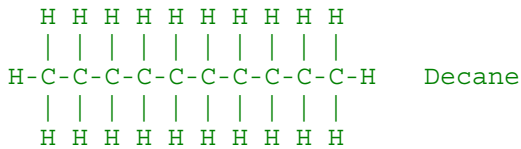
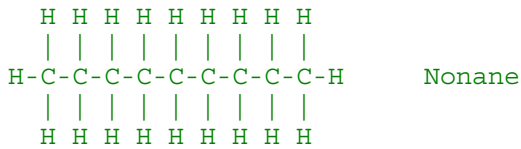
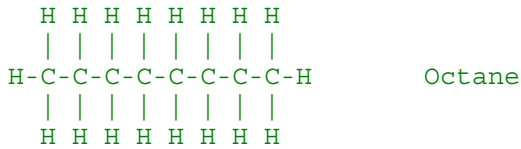
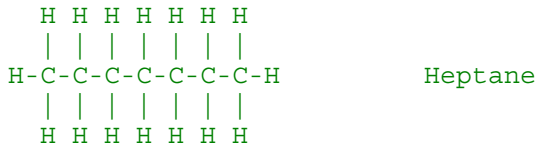


## GASOLINE:

Energy content: 43 to 47 KJ/gram not much different from candlewax or candybars  
(physical density of gasoline is about .73 times that of water (.73 g/cc...it floats!).

Coal...15 to 19 KJ/gram



Typical molecules found in gasoline

## 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 <sup>2</sup> 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	$1.3 \times 10^8$
AA battery	$10^3$
standard cubic foot of natural gas (SCF)	$1.1 \times 10^6$
candy bar	$10^6$
barrel of crude oil (contains 42 gallons)	$6.1 \times 10^9$
pound of coal	$1.6 \times 10^7$
pound of gasoline	$2.2 \times 10^7$
pound of oil	$2.4 \times 10^7$
pound of Uranium-235	$3.7 \times 10^{13}$
ton of coal	$3.2 \times 10^{10}$
ton of Uranium-235	$7.4 \times 10^{16}$

## 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 hphr	$2.68 \times 10^6$ joules	or	0.746 kwh		
1 kwh	$3.61 \times 10^6$ joules	or	3413 Btu		
1 eV	$1.61 \times 10^{-19}$ joules				

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

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

**=  $2.53 \times 10^{14}$  joules/day =  $2.9 \times 10^9$  watts =  
2200 Mwatts thermal fuel energy**

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:  $2.4 \times 10^8$  SCF/day

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

Note: 1000 MWe utility, at 60% load factor, =  $6 \times 10^5$  kw generates  $5.3 \times 10^9$  kwh/year, enough for a city of about 1 million people in the U.S.A .

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

## Geographic Energy Needs

U.S. Total Energy Consumption (1990)

=  $82.1 \times 10^{15}$  Btu (82.1 Quads) = 38.8 MBPD oil equivalent =  $86.6 \times 10^9$  GJ = 86.6 exaJoule; (recall 1 Quad is a quadrillion ( $10^{15}$ ) BTU or 1.055 exaJoules ( $1.055 \times 10^{18}$  Joules)). Since 1990 we've gone up....global energy consumption (marketable energy) is almost 400 exaJoules in 2000.

## **Everyday Usage and Energy Equivalencies Everyday Usage and Energy Equivalencies**

---

1 barrel of oil = 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**

---

90 pounds of coal

125 pounds of oven-dried 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 Occurrences

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	$10^{23}$
Annual tidal friction	$10^{20}$
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	$10^{15}$

## 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	$10^{23}$
Annual tidal friction	$10^{20}$
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	$10^{12}$

<i>Saturn V</i> 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	$10^3$
IAA 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	Uses
Electricity	1 Kwh	\$0.10	appliances, motors
Gasoline	1 gallon	1.20	transportation
Natural Gas	1 Therm	0.60	heating
AA battery	1 battery	0.80	portable electronics
Milky Way candy bar	1 bar	0.60	food

## Worldwide Power Use-History

"Developed" countries average (1990):

- 1.2 billion people 7.5 kilowatts/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 day!..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<sup>2</sup> (an area 100 m x 100 m, or 328 x 328 ft) = 2.47 acres
  - 1.0 km<sup>2</sup> = 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<sup>2</sup> = 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<sup>2</sup>)
- 

## Biomass energy

- **Cord:** a stack of wood comprising 128 cubic feet (3.62 m<sup>3</sup>); 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 **wood** = 1.4 cubic meters (solid wood, not stacked)
  - Energy content of **wood fuel** (HHV, bone dry) = 18-22 GJ/t (7,600-9,600 Btu/lb)
  - Energy content of **wood fuel** (air dry, 20% moisture) = about 15 GJ/t (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<sup>3</sup>)
- Metric tonne **biodiesel** = 37.8 GJ (33.3 - 35.7 MJ/liter)
  - biodiesel density (average) = 0.88 g/ml (= metric tonnes/m<sup>3</sup>)

## Fossil fuels

- **Barrel of oil** equivalent (boe) = approx. 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. "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). HHV = 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<sup>3</sup>)
  - **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<sup>3</sup>)
  - 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/ft<sup>3</sup> = 38.3 MJ/m<sup>3</sup>; LHV = 930 Btu/ft<sup>3</sup> = 34.6 MJ/m<sup>3</sup>
    - 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