École Polytechnique
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PHY 555 — Energy and Environment

PC1 — Orders of magnitude

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Slides of the tutorial sessions are available on Moddle:
https://moodle.polytechnique.fr/course/view.php?id=14012

This first session comes in the form of small guessing. The goal is to determine by yourself in each case, what are the important processes and how to estimate their contribution. More than the numerical values, these are the orders of magnitude that matter. All exercises will not be corrected during the tutorial session.

1 – Everyday life

1. What is the average energy expended by a human being (in one second)? What typical work can a person accomplish in a given time (e.g., climb the steps of Lozère — 60 m in about 10 min.)? On a nutritionist website, energy consumption for a sustained physical activity such as stepper (stepper) is given as 633 kcal/h for an individual of 70 kg. For the bike ride at the speed of 30 km/h, the same individual would consume 813 kcal/h. Estimate the yield of the “human machine”. How much water should the cyclist drink per hour?
2. Can we deduce for the previous an estimate of the power of a horse? What is the power required to sustain the speed of a car at 130 km/h on flat ground (in Joules, then *horsepower)?*[1]What then is the consumption of the vehicle? Is this realistic? What is the power required for a semi-trailer (36 tons) to reach a speed of 90 km/h in a minute? What would be the impact on fuel consumption of a 10% reduction in average speed?

2 – Energy Sources

1. Let's consider a wind turbine of radius r, placed in an average wind speed v. Estimate, as a function of the wind speed, the recoverable power. The largest wind turbines[2] have a radius of ~ 80 m, (eg Vestas V164, 8MWe, Ø = 164 m), for average winds on the sea about 30 km/h. Estimate the potential of such a wind turbine.
2. In 2012, there were 7.2 GWe of installed wind turbines that produced 14.9 TWh of electricity. What is the load factor? How many turbines would it take to replace the Flamanville EPR (1650 MWe) and what would be the cost of installation? The installed cost of a wind turbine is around at 1.5 €/kWhe. What about the entirety of French electricity production?
3. The Three Gorges Dam, located on the Yellow River, is 100 m high and 2300 m wide. The flow of the river is 15 000 m^3/s (Wikipedia). Estimate the power of the dam. How many windmills does it represent? Its construction required 27 million cubic meters of concrete. Embodied energy (i.e., required for the manufacturing, transportation and installation) being estimated at 1.5 GJ/m^3 for concrete, give an order of magnitude of the energy payback time of the dam.
4. Plants produce sugar by photosynthetic reaction. The balance of photosynthesis is written in the form 6 CO_2 + 12 H_2O + light → $C_6H_{12}O6$ (glucose) + 6 O_2 + 6 H_2O. It takes about 9-10 visible

1 One horsepower is the power needed to lift the mass of 75 kg at a speed of 1 m / s in the Earth's gravitational field
2 eg.VESTAS V164, 8MWe, Ø = 164 m

photons (~yellow) to produce one molecular oxygen molecule. The energy contained in one mole of glucose is 2871 kJ (or 686 cal). What is the efficiency of photosynthesis? Biside this purely photosynthetic efficiency, what do we need to take into account to estimate biomass production?

3 – Consumption

1. Global oil consumption is currently 4 Gtoe for estimated reserves of 150 billion toe. After how long will these reserves exhausted (under the assumption of a growth of consumption of 2% per year)? And constant consumption? Taking into account other forms of fossil energy, primary energy consumption is estimated at 11 billion toe for ultimate reserves (proven and supposed) of 4000 Gtoe (largely in the form of coal). How long can we hold?

4 – Astrophysics

1. The sun is modelled as black body at the temperature of 5800 K. What is the total power radiated by the sun? If this power was of chemical origin, what would be the order of magnitude of the lifetime of the Sun? The source of solar energy was one of the main riddles of the early years of the modern scientific era. In the nineteenth century, Lord Kelvin quickly realized the chemistry was not powerful enough to account for the age of the sun. He proposed a mechanism based on the gravitational contraction, considering that the age of the sun was close to its gravitational energy divided by the emitted power. What age estimation would that give? There ensued a controversy with geologists, especially proponents of the theory of evolution, who estimated the age of the Earth at more than 2 billion years. Now the lifetime of the sun is estimated to be about 10 billion years. What is the magnitude of the energy involved in the reaction between protons):

Astrophysics Data

Moon :

Mass : 7,349×10^{22} kg

Distance Earth – Moon (centre to centre) :384 403 km

Equatorial Diameter : 3 474,6 km

Sun :

Average Diameter : 1 392 000 km

Area : 6,09×10^{12} km^2

Volume : 1,41×10^{18} km^3

Mass ($M_{\odot}$): 1,9891×10^{30} kg

Surface Temperature : 5800 K

Radiated Power : 3,826×10^{26} W

Earth :

Equatorial Radius : 6 378,1 km

Polar Radius : 6 356,7 km

Volume : 1,08 321×10^{12} km^3

Mass : 5,9736×10^{24} kg

Average density : 5,515×10^3 kg/m^3

Axis inclination : 23,4392°

Half major axis : 149 597 887,5 km

Eccentricity : 0,01 671 022

Average Orbital Speed : 29,783 km/s

Average Albedo : 0,367

Average Surface Temperature : 288 K = 15°C

Energy data

1 ton TNT = 4.186×10^9 J

1 toe = 41 855×10^6 J

1eV = 1.6×10^{-19} J

1 calory = 4,2 J

Stefan constant :
$\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}

Universal constant of Gravitation :
$G = 6.6742\times10^{-11}$ m^3 kg^{-1} s^{-2}

Avogadro's number :
N = 6.02 ×10^{23} mol^{-1}

Absolute Zero :
T_0 = -273,15 °C

Planck constant :
$h \approx 6{,}626\ 0\ 755\times10^{-34}$ J.s

total primary energy consumption :
11 Gtoe (2006)

Other Data

Density of air :
$\rho(15°)$ = 1,225 kg m^{-3}

Vaporization enthalpy of water :
$\Delta H_V(30°)$ = 2430 kJ kg^{-1}

Perfect gas constant :
R = 8,314 J mol^{-1} K^{-1}