E&ES 199 - INTRO TO ENVIRONMENTAL SCIENCE

ENERGY DEMAND AND SUPPLY: SUMMARY

Conventional fossil fuel energy is largely contained in oil, gas and coal, whereas the unconventional resources are oil shales and 'tight-sands' (gas reservoirs). We will later discuss the origin of the fossil fuel resources. The fossil fuel supplies are categorized as **energy reserves** (known deposits that can be exploited at a profit with today's technology) versus **energy resources** (known deposits that are not yet economical or hypothesized deposits that are as yet unproven). Table 1 gives an overview of the world's major energy sources by type and by country, and Table 2 gives a world energy summary for oil, gas and coal, but now all expressed in the same units (quad=10^{15} BTU ~ 10^{18} Joules). Obviously, Russia, the USA and the Middle East are the leading suppliers of world energy now and in the future; China has probably large coal resources as well. It is also obvious that coal contains the largest energy supply.

Energy demand can be phrased by country in Watts or Quads/year (power units - watt = Joule/sec), or as *per capita*[*] energy demand per country or average worldwide. The total world energy demand is on the order of 350 Quads/year, whereas the USA has a demand of about 95 Quads/year (<5 % of the world population uses ~25% of the world's energy supply). When we compare GNP with *per capita* energy demand, Canada and the US were among the top scorers in *per capita* GNP $ but with a high ratio of energy demand/GNP$. One reason for that energy hunger is the demography-large countries with low population density-> intrinsic high transportation costs, enhanced by V8-SUVs. The *per capita* energy demand in the US is about 12 kW, whereas the less developed countries have on the order of 0.5 kW *per capita* demand. A full-blown human effort is about 120 watts, so each USA citizen holds about 100 'energy slaves' to satisfy his/her daily needs (versus 5 in the LDC), which suddenly makes the price of fossil fuel seem dirt cheap.

Table 3 puts the different energy fluxes in the terrestrial environment into perspective: solar heat flux, subdivided among various atmospheric processes, terrestrial heat flow and tidal energy fluxes, and the energy use of 'personkind'. Fossil fuel is "fossilized solar energy", and the photosynthetic flux is only a small % of the total received solar energy. This by itself suggests that we should take a better look at primary or direct solar energy usage.

How to calculate the “expiration time of fossil fuels"? I derived that for you on a sunny Sunday afternoon. We gained some insights into the nature of population growth: exponential growth, expressed as $\mathbf{N = N_o e^{rt}}$

(eq. 1)

where r is the annual % population growth (subscript o stands for "now"). To phrase future energy demand (ED), we can develop an expression of the same

---

[*] the Latin term “*per capita*” is in common use, meaning “per head”. It is however an irregular plural form (*caput* in Latin is singular for “head”), so we say in effect “ per heads”!

form as eq. 1, because global energy demand is N x *pc* ED. So as a first approximation,

$$\mathbf{ED = ED_o\, e^{rt}} \qquad \text{(eq. 2)}$$

with $\mathbf{ED_o = N_o \times pc\text{-}ED_o}$.

It is unlikely that *pc* -ED remains constant over time, and we should figure that into eq. 2. We can use (crudely) a parameter r' which depends on the rate of population growth and also contains the change in *pc* energy demand. Strictly speaking, this may be wrong, because the *pc* energy demand will probably not increase exponentially worldwide for a long time, but will increase in some unpredictable way. In the US in 1972, population increased 1%, whereas energy use increased by 4.5 %. Between 2000 and 2004, the US population increased with 1 % and the energy demand increased by 1 %, so clearly the pc energy demand remained constant. Worldwide, however, the population increased by 1.4 % per year whereas the energy demand increased by 1.7% per year. This makes all sense, because we have reached somewhat the limit of how many cars we can drive at the same time, whereas the developing world is just buying their first motorcycle or small car. Exact expressions on future ED have N and *pc* ED as separate terms, and each of the two growth rates r are expressed with their own specific time dependency, leading to sigmoidal type growth curves.

We can calculate how long fossil fuel energy resources "will last" when we cumulate the total energy demand over future time. We could use three approximations, listed in increasing degree of complexity (closer to the truth??):

I. Divide current estimates of total energy resources (ER_{tot}) by today's ED_o --> a strong underestimate of future ED giving an overly optimistic energy picture.

II. Set the total future energy usage equal to the total energy resources, that is, integrate the exponential energy demand equation 2 from ‘now’ to its EET (exponential expiration time = T_e) and solve for T_e by saying

$$\mathbf{ER_{tot} = \int ED_o\, e^{r't}\, dt} \qquad \text{(eq. 3)}$$

III. Use the full and complex expression for ED, and integrate that one as a function of time (more difficult) and equate to ER_{tot}.

For the *non calculus-conoscenti* among you, integration is a form of addition, where you divide the future time into tiny slices with length dt and add (or cumulate) the changing energy demand for all these small time slices. This is the same as calculating the surface area under a curve in a graph with axes for time and ED (figure 1).

You can look up the integral of eq. 3 in a calculus book and then you have to fill in the begin and end values for time, in our case the starting time (taken as time =0, which is ‘now’) and T_e. We then obtain

$$\mathbf{ER_{tot} = ED_o \{e^{r'T_e} - 1\} / r'} \qquad \text{(eq. 4)}$$

Now we are ready to get the final expression and we solve for T_e and switch from e-based logarithms to 10-based logarithms:

$$\mathbf{T_e = (2.303 / r') \log \{(r' ER_{tot} / ED_o) + 1\}} \qquad \text{(eq. 5)}$$

Now this is an equation to be proud of, and for each value of r' we can calculate the EET for a given energy resource base (oil, gas, coal, nuclear) and the known current demand for that energy supply; we can do the same for the total sum of the energy resources. With the rates of population growth of the 1990s (1.6 % or r = 0.016) and a 'guess' for the influence of increased pc ED with time (e.g., r' = 0.02 and r’ = 0.05), I calculated with the best estimate ER values of Table 2 the EET for oil, gas, coal, nuclear and total conventional energy. I also listed the results of the simplistic approach (ER_{tot} / ED_o), which gives longer and probably unrealistic expiration times. The T_e for the different energy sources do not add up to the total T_e, because when a given energy resource is exhausted, the world will switch to another one.

The fossil fuel energy resources will last at least 100-200 years, but a much larger and more direct concern may be the pollution associated with fossil fuel energy usage. These are mainly CO_2 emissions (greenhouse gas--climate change) and SO_2 emissions, the latter largely from coal, giving acid rain, not to talk about nitrogen oxides and smogs, particulates and trace metal pollution. We discuss solar, wind, geothermal, and hydro energy options as energy alternatives later.

Table 1. Conventional fossil fuel supplies (reserves + resources)

Country	Oil, 10^9 barrels	coal, 10^9 tons	gas, 10^{12} ft^3
USA	210	1460	2740
former USSR	270	2540	3750
Middle East	1370	-	2480
Mexico	230	4	510
Total	**2080**	**4004**	**9480**

The resources are very uncertain, the reserves are here and will be used.

Table 2. Global energy resource estimates (exajoules/quads) and simple expiration times (SET) and exponential expiration times (EET) at 2 and 5 % intrinsic annual growth rates, based on 'best estimates' for resource. Constant energy demand distribution: coal 30 %, oil 40 %, gas 25 % and nuclear 5 %, with a current energy demand of 350 quads/yr. SET and EET in years [#]

Resource	Low Estim.	Best Estimate	High Estim.	ED_o	SET 0 %	EET 2 %	EET 5 %
oil	9,800	13,400	34,300	140	446	53	35
gas	6,300	11,400	17,300	88	130	64	40
coal		330,000		105	3143	208	101
nuclear[&]		12,600		17	740	138	73
TOTAL		**367,400**		**350**	**1050**	**155**	**80**
gas*	700	?	7,100				
oil*		2,100,000					

* unconventional gas and oil; [&]nuclear fission only

Table 3. Different sources of energy for the earth

10^{13} Watts	Total	heat	wind	evap	photosyn.
solar	12100	8000	37	4000	4
Earth Heat	3.2				
Tidal	0.3				
En. Demand USA	0.3				

[#] Courtesy of the Windmill Calculation Studios, not Inc; CEO: Don Quichote

Figure 1. Energy demand for 2% and 5 % growth rates per year

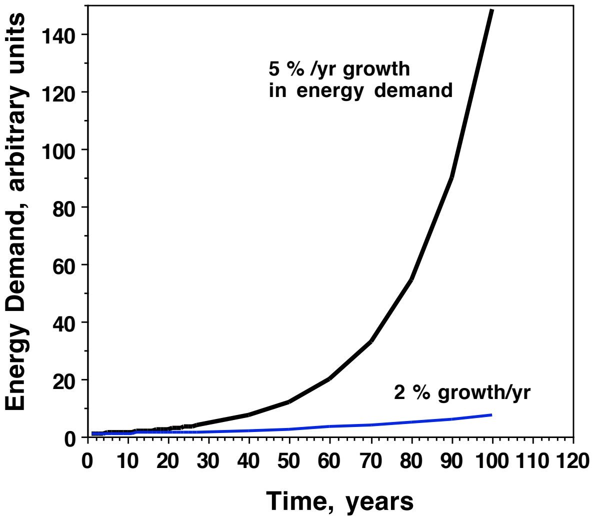

Figure 2. Energy demand curve as a function of time with arbitrary units. The cumulative energy consumption is the summation of all the slices of t x demand, with one example slice shown. You can see that the demand is slightly higher in 82 than in 80, so the two year slice can be multiplied with the energy demand in 81. When we take the time unit very small, the energy demand is constant per very narrow slice, so we can approximate the integral by summing the small slices.