Joules, Watts and Kilowatthours

Basics

When we talk about **energy**, we often mean really **power** = energy / time. Let's first see what the basic units are, how they can be expressed and how they are connected. The links take you to the modules of the Hyperscript "Einführung in die Materialwissenschaft I", where more details can be found

Units for Energy, Power, and Electricity

Quantity	**Name**	**Symbol**	**Units**		**Relations**
			In basic units	In secondary units	
Energy	Joule	J	$m^2\ kg\ s^{-2}$	N · m	1 kWh = 3.6 · 10^6 J
				W · s	1 kcal = 4,1868 kJ = 1,163 kWh
					1 to ***SKE*** = 8 140 kWh
Power	Watt	W	J/s	$m^2\ kg\ s^{-3}$	1 kW = 3.15 · 10^{10} J/yr 1 kW = 3.6 · 10^6 J/hr 1 kW = 10^6 J/s
				V · A	
Electric potential, voltage	Volt	V	W/A	$m^2\ kg\ s^{-3}\ A^{-1}$	
Time	Second	s	s	s	1 yr = 1 a = 3.15 · 10^7 s 1 d = 86 400 s

There are a few points to note:

- The time unit is the second or "**s**". Then we have the minute = "**m**", the hour = "**h**" and the day = "**d**" as officially (allowed) **SI** units. There is no official abbreviation for year; here we use either "**yr**" or "**a**" (for annum).
- Terms like **energy consumption** do not mean (of course!) that energy is really *consumed*, but that it is just transformed (to heat in the end). There is such a thing as the energy conservation law, after all!
- In case of doubt, when just the term "energy" is used, what is meant is often *energy per year* - formally this is *power*. However, it is not always sensible to refer to formal "power" as power: If your gas tank contains ***x*** liters of gasoline, it contains some equivalent of pure *energy*. If your *consumption* of gasoline is **2 000 l** *per year*, you talk about the energy *per year* that you have consumed (about **20 000 kWh**)! You could express that as an *average* consumption of **2 000/3,15 · 10^7 l/s = 6,5 · 10^{-5} l/s** in **SI** units - but that doesn't make much sense.
- There is **primary energy** and **secondary energy**. If your personal consumption of electrical energy is, for example, **2 000 kWh** (*per year*; a good number for an average German), then this is what your power company charges your for. In this case you are charged for your use of *secondary* (electrical) energy. The *primary* energy needed for producing that amount of *secondary* energy (per year!), is roughly *three times* larger, because the ***efficiency*** of our fuel-burning power plants is around **35 %**. This means that in terms of the energy contained in coal, oil or gas - whatever was burnt to produce your personal **2 000 kWh** (*per year*), you actually consumed around **6 000 kWh** (*per year*).
- Your **direct** consumption of these secondary **2 000 kWh**, that you paid for directly, is not all the electrical energy that you personally consumed (*per year*; last time!). You also consumed electrical energy in the form of light at the place you work, products you buy (that somebody made somewhere, using electrical energy), and so on. Your *indirect* (secondary) electrical energy consumption is probably much higher than your *direct* consumption - about a factor of **2,5**.
- Besides electrical energy, *you*, personally, consumed energy in the form of heat (including hot water for showers), gasoline (for driving your car and for riding a bus and so on) eating and drinking (somebody had to ride a tractor to harvest the hops, transport your beer, and so on); *your* grand total of primary energy consumption is around **50 000 kWh** (per year) - if you are a German or **EU** citizen. If you are an American, it's **2,5** times more; it's far less if you are, e.g., from Ghana or Peru

We have now defined the *quality* of energy and power; next let's get a feeling for the **quantities** involved.

We will not care about *precise* numbers. If humankind right now consumes **13 TW**, **12,8 TW** or already **14,783 TW**, is just as irrelevant in this context, as the question if the **50 W** of power produced by the slave mentioned below includes his sleeping time, or only the time he actually works.

Typical examples for energy and power			
Example		**Formula**	
Energy *E*	Potential energy E_{pot} if *I* climb h **= 1.000 m** (For *you* it might be a little less)	$E_{pot} = m \cdot g \cdot h$ $= 100\ kg \cdot 9{,}81\ m/s^2 \cdot 1000\ m$ $= 9{,}81 \cdot 10^5\ J$ **= 0,273 kWh**	
1 kWh corresponds to:		367 t lifted to 1 m 9,5 l water à 10^{o}C bring to boil 2 km - 10 km car driving	
1 kWh is **stored** in:		Large (85 Ah) truck batterie 0,1 l gasoline / Diesel 0,25 kg dry wood 0,12 m^3 natural gas 0,28 m^3 H_2 7,3 t H_2O in a reservoir with 50 m height difference	
Power *P*	What *I* can sustain for ≈ **1 hr** on a bicycle	**175 W**	
	Hard working **slave** on average	**50 W**	
Power consumed by a **light**.		≈ **50 W**	
Power consumed by a **toaster**.		≈ **1 kW**	
Energy consumed by a toaster in **3** minutes		**50 Whr**	
Time your **slave** has to work to power your toaster for **3 min**.		**1 hr**	
Power consumed by your **car**		≈ **20 kW - 100 kW**	
Power consumed by a (small) **jet engine**		≈ **1 000 kW**	
Output of "standard" **power plant**.		≈ **1 000 000 kW = 1 GW**	
Global secondary *electrical* power demand.		**1 000 GW =** 10^{12} **W = 1 TW**	
		1 "**Terawatt**" = 1 trillion Watt (USA) = 1 Billion Watt (Europe)	
Total *primary* global **power** produced (**2001**) Oil: 4,66 TW Gas 2,89 TW Coal 2,98 Nuclear 0,92 TW Rest: 1,81 TW		**13 TW**	
		USA (303 Mill. people)	**3,2 TW**
		Rest (6.331 Mill. people)	**9,8 TW**
Total **energy** produced (= consumed) *per year* in **2001** (**EJ = Exa Joule =** 10^{18} **J**)		**13 TW ·** $3{,}15 \cdot 10^7$ **s =** $4 \cdot 10^{20}$ **J/yr = 400 EJ/yr**	
Total **energy** produced (= consumed) **per year *and capita*** USA: **350 GJ/yr = 97 200 kWh/yr** Australia: **240 GJ/yr = 66 600 kWh/yr** Japan; ***EU***; S.-Korea: **150 GJ/yr = 41 700 kWh/yr** Brazil: **40 GJ/yr = 11 100 kWh/yr** China: **30 GJ/yr = 8 330 kWh/yr** India: **15 GJ/yr = 4 170 kWh/yr**		**60 GJ/yr · capita = 16 660 kWh/yr · capita**	
Time it takes if we built **1** renewable standard **1 GW** power plant per day on Terra to replace all "carbon emission" power plants		**11 TW / 1 GW = 11 000 days** **= 30 years**	

Total **energy** needed (*per year*) in **2050**	Who knows? Extrapolation: All like **EU**:	**33 TW**
Additional power plant building rate needed to account for the expected increase.	**22 TW / 1 GW · 50 yr = 1.2 power plants / day**	
Present (**2007**) rate of **1 GW** solar cell power plants built per day	**$3 \cdot 10^{-4}$ power plants / day**	
Conclusion:	*You*, the young student, are in trouble! (*I*, the old professor, will get by)	

- What you find in this table you may call the "The Terawatt Challenge", and it has been called this way. Read more about it in the article Future Global Energy Prosperity: The Terawatt Challenge of Nobel prize winner **Richard Smalley** published in the **MRS** Bulletin **30, 2005**, and in the article "Powering the Planet" of **Nathan S. Lewis** in the **MRS** Bulletin **32, 2007**

- This looks like somebody should do something. Right. This somebody is *you* - and *you*, over there in the **USA**, too!

- While the shear magnitude of the numbers may induce a feeling of hopelessness, fixing the problem within the next **50** years or so is *not* impossible. Let's look at the bright side:
  - *Building power plants:* Build one big **1 GW** power plant *per day*?? Impossible! Wrong - that's exactly what we have been doing for many years! The energy - time curve in the past had the same slope we used for the extrapolation, roughly **1 GW/day**. So it can be done, and if we really want to do it (and pay the higher price!) we can do it with renewable energy plants, too, in the not-so-distant future.
  - *Reducing energy consumption:* You (and I) don't really need **50 000 kWh/year** or even more to experience a high quality of life. The average quality of life in the **USA** is certainly not higher than in the **EU**, but energy consumption is more than **2** times larger. In **1970** *I*, personally, had a pretty good life, too - but consumed far less energy than I do now. So let's reduce energy consumption without compromising the quality of life - it can be done!
  - *Renewable energy is too expensive:* Bullshit! It is nominally more expensive than *my*, the old Professor's, present **kWh** price - yes! But I'm not paying the full bill; it does not include, for example, the cost of climate change or the destruction of the environment, the costs of the wars for resources etc. -Either *you*, the young student, will have to pay for this later, or all of us pay somewhat more soon.
  - *Slave labor:* A slave could give you **50 W · 24 · 365 hr = 438 kWh/year** if you worked him really hard (your female slave may give you things not always measured in **W**). You European thus command **114** slaves working all the time for you; even more if you let them go to the bath room on occasion. You have this much power at your fingertips *only* because you have access to technology. Think a moment about this! It is the *only* reason why *you*, personally, are doing so well in modern society! In good old-fashioned society, only one out of **114** or more could command that much *power*, so chances are **> 114 : 1** that *he* was your Lord and *you* one of his slaves / serfs / indebted servants, or whatever you like to call it.
  - *Exponential growth:* Nobody has a feeling for exponential growth - you must sit down and calculate. OK. Here is the exercise:
(Look at least at the solution!)

Exercise b8_1_1
Exponential growth