I Quick reference

SI Units

> **The watt.** This SI unit is named after James Watt. As for all SI units whose names are derived from the proper name of a person, the first letter of its symbol is uppercase (W). But when an SI unit is spelled out, it should always be written in lowercase (watt), with the exception of the "degree Celsius."
>
> from wikipedia

SI stands for Système Internationale. SI units are the ones that all engineers should use, to avoid losing spacecraft.

SI units		
energy	one joule	1 J
power	one watt	1 W
force	one newton	1 N
length	one metre	1 m
time	one second	1 s
temperature	one kelvin	1 K

prefix	kilo	mega	giga	tera	peta	exa
symbol	k	M	G	T	P	E
factor	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}

prefix	centi	milli	micro	nano	pico	femto
symbol	c	m	μ	n	p	f
factor	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}

Table I.1. SI units and prefixes

My preferred units for energy, power, and transport efficiencies

	My preferred units, expressed in SI		
energy	one kilowatt-hour	1 kWh	3 600 000 J
power	one kilowatt-hour per day	1 kWh/d	$(1000/24)$ W $\simeq$ 40 W
force	one kilowatt-hour per 100 km	1 kWh/100 km	36 N
time	one hour	1 h	3600 s
	one day	1 d	$24 \times 3600\,\text{s} \simeq 10^5\,\text{s}$
	one year	1 y	$365.25 \times 24 \times 3600\,\text{s} \simeq \pi \times 10^7\,\text{s}$
force per mass	kilowatt-hour per ton-kilometre	1 kWh/t-km	$3.6\,\text{m/s}^2$ ($\simeq 0.37g$)

Additional units and symbols

Thing measured	unit name	symbol	value
humans	person	p	
mass	ton	t	1 t = 1000 kg
	gigaton	Gt	1 Gt = 10^9 × 1000 kg = 1 Pg
transport	person-kilometre	p-km	
transport	ton-kilometre	t-km	
volume	litre	l	1 l = 0.001 m^3
area	square kilometre	sq km, km^2	1 sq km = 10^6 m^2
	hectare	ha	1 ha = 10^4 m^2
	Wales		1 Wales = 21 000 km^2
	London (Greater London)		1 London = 1580 km^2
energy	Dinorwig		1 Dinorwig = 9 GWh

Billions, millions, and other people's prefixes

Throughout this book "a billion" (1 bn) means a standard American billion, that is, 10^9, or a thousand million. A trillion is 10^{12}. The standard prefix meaning "billion" (10^9) is "giga."

In continental Europe, the abbreviations Mio and Mrd denote a million and billion respectively. Mrd is short for milliard, which means 10^9.

The abbreviation m is often used to mean million, but this abbreviation is incompatible with the SI – think of mg (milligram) for example. So I don't use m to mean million. Where some people use m, I replace it by M. For example, I use Mtoe for million tons of oil equivalent, and Mt CO_2 for million tons of CO_2.

Annoying units

There's a whole bunch of commonly used units that are annoying for various reasons. I've figured out what some of them mean. I list them here, to help you translate the media stories you read.

Homes

The "home" is commonly used when describing the power of renewable facilities. For example, "The £300 million Whitelee wind farm's 140 turbines will generate 322 MW – enough to power 200 000 homes." The "home" is defined by the British Wind Energy Association to be a power of 4700 kWh per year [`www.bwea.com/ukwed/operational.asp`]. That's 0.54 kW, or 13 kWh per day. (A few other organizations use 4000 kWh/y per household.)

The "home" annoys me because I worry that people confuse it with *the total power consumption of the occupants of a home* – but the latter is actually about 24 times bigger. The "home" covers the average domestic *electricity* consumption of a household, only. Not the household's home heating. Nor their workplace. Nor their transport. Nor all the energy-consuming things that society does for them.

Incidentally, when they talk of the CO_2 emissions of a "home," the official exchange rate appears to be 4 tons CO_2 per home per year.

Power stations

Energy saving ideas are sometimes described in terms of power stations. For example according to a BBC report on putting new everlasting LED lightbulbs in traffic lights, "The power savings would be huge – keeping the UK's traffic lights running requires the equivalent of two medium-sized power stations." `news.bbc.co.uk/1/low/sci/tech/specials/sheffield_99/449368.stm`

What is a medium-sized power station? 10 MW? 50 MW? 100 MW? 500 MW? I don't have a clue. A google search indicates that some people think it's 30 MW, some 250 MW, some 500 MW (the most common choice), and some 800 MW. What a useless unit!

Surely it would be clearer for the article about traffic lights to express what it's saying as a percentage? "Keeping the UK's traffic lights running requires 11 MW of electricity, which is 0.03% of the UK's electricity." This would reveal how "huge" the power savings are.

Figure I.2 shows the powers of the UK's 19 coal power stations.

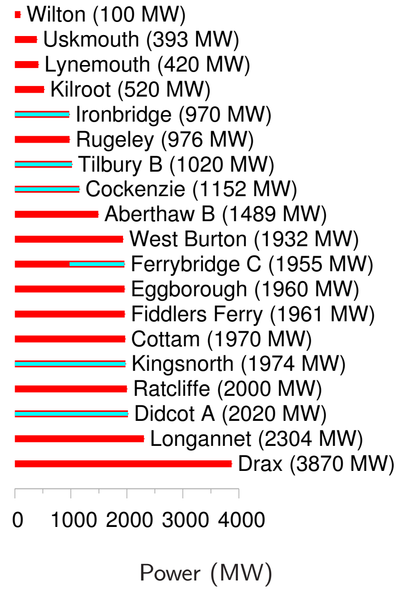

Figure I.2. Powers of Britain's coal power stations. I've highlighted in blue 8 GW of generating capacity that will close by 2015. 2500 MW, shared across Britain, is the same as 1 kWh per day per person.

Cars taken off the road

Some advertisements describe reductions in CO_2 pollution in terms of the "equivalent number of cars taken off the road." For example, Richard Branson says that if Virgin Trains' Voyager fleet switched to 20% biodiesel – incidentally, don't you feel it's outrageous to call a train a "green biodiesel-powered train" when it runs on 80% fossil fuels and just 20% biodiesel? – sorry, I got distracted. Richard Branson says that *if* Virgin Trains' Voyager fleet switched to 20% biodiesel – I emphasize the "*if*" because people like Beardie are always getting media publicity for announcing that they are *thinking of* doing good things, but some of these fanfared initiatives are later quietly cancelled, such as the idea of towing aircraft around airports to make them greener – sorry, I got distracted again. Richard Branson says that *if* Virgin Trains' Voyager fleet switched to 20% biodiesel, then there would be a reduction of 34 500 tons of CO_2 per year, which is equivalent to "23 000 cars taken off the road." This statement reveals the exchange rate:

$$\text{"one car taken off the road"} \longleftrightarrow -1.5 \text{ tons per year of } CO_2.$$

Calories

The calorie is annoying because the diet community call a kilocalorie a Calorie. 1 such food Calorie = 1000 calories.

$$2500\,\text{kcal} = 3\,\text{kWh} = 10\,000\,\text{kJ} = 10\,\text{MJ}.$$

Barrels

An annoying unit loved by the oil community, along with the ton of oil. Why can't they stick to one unit? A barrel of oil is 6.1 GJ or 1700 kWh.

Barrels are doubly annoying because there are multiple definitions of barrels, all having different volumes.

Here's everything you need to know about barrels of oil. One barrel is 42 U.S. gallons, or 159 litres. One barrel of oil is 0.1364 tons of oil. One barrel of crude oil has an energy of 5.75 GJ. One barrel of oil weighs 136 kg. One ton of crude oil is 7.33 barrels and 42.1 GJ. The carbon-pollution rate of crude oil is 400 kg of CO_2 per barrel. `www.chemlink.com.au/conversions.htm` This means that when the price of oil is $100 per barrel, oil energy costs 6¢ per kWh. If there were a carbon tax of $250 per ton of CO_2 on fossil fuels, that tax would increase the price of a barrel of oil by $100.

Gallons

The gallon would be a fine human-friendly unit, except the Yanks messed it up by defining the gallon differently from everyone else, as they did the pint and the quart. The US volumes are all roughly five-sixths of the correct volumes.

1 US gal = 3.785 l = 0.83 imperial gal. 1 imperial gal = 4.545 l.

Tons

Tons are annoying because there are short tons, long tons and metric tons. They are close enough that I don't bother distinguishing between them. 1 short ton (2000 lb) = 907 kg; 1 long ton (2240 lb) = 1016 kg; 1 metric ton (or tonne) = 1000 kg.

BTU and quads

British thermal units are annoying because they are neither part of the *Système Internationale*, nor are they of a useful size. Like the useless joule, they are too small, so you have to roll out silly prefixes like "quadrillion" (10^{15}) to make practical use of them.

1 kJ is 0.947 BTU. 1 kWh is 3409 BTU.

A "quad" is 1 quadrillion BTU = 293 TWh.

Funny units

Cups of tea

Is this a way to make solar panels sound good? "Once all the 7 000 photovoltaic panels are in place, it is expected that the solar panels will create 180 000 units of renewable electricity each year – enough energy to make **nine million cups of tea**." This announcement thus equates 1 kWh to 50 cups of tea.

As a unit of volume, 1 US cup (half a US pint) is officially 0.24 l; but a cup of tea or coffee is usually about 0.18 l. To raise 50 cups of water, at 0.18 l per cup, from 15 °C to 100 °C requires 1 kWh.

So "nine million cups of tea per year" is another way of saying "20 kW."

Double-decker buses, Albert Halls and Wembley stadiums

"If everyone in the UK that could, installed cavity wall insulation, we could cut carbon dioxide emissions by a huge 7 million tons. That's enough carbon dioxide to fill nearly 40 million double-decker buses or fill the new Wembley stadium 900 times!"

From which we learn the helpful fact that one Wembley is 44 000 double decker buses. Actually, Wembley's bowl has a volume of 1 140 000 m^3.

"If every household installed just one energy saving light bulb, there would be enough carbon dioxide saved to fill the Royal Albert Hall 1,980 times!" (An Albert Hall is 100 000 m^3.)

Expressing amounts of CO_2 by volume rather than mass is a great way to make them sound big. Should "1 kg of CO_2 per day" sound too small, just say "200 000 litres of CO_2 per year"!

mass of CO_2	↔	volume
2 kg CO_2	↔	1 m^3
1 kg CO_2	↔	500 litres
44 g CO_2	↔	22 litres
2 g CO_2	↔	1 litre

Table I.3. Volume-to-mass conversion.

More volumes

A container is 2.4 m wide by 2.6 m high by (6.1 or 12.2) metres long (for the TEU and FEU respectively).

One TEU is the size of a small 20-foot container – an interior volume of about 33 m^3. Most containers you see today are 40-foot containers with a size of 2 TEU. A 40-foot container weighs 4 tons and can carry 26 tons of stuff; its volume is 67.5 m^3.

A swimming pool has a volume of about 3000 m^3.

One double decker bus has a volume of 100 m^3.

One hot air balloon is 2500 m^3.

The great pyramid at Giza has a volume of 2 500 000 cubic metres.

Figure I.4. A twenty-foot container (1 TEU).

Areas

The area of the earth's surface is 500×10^6 km^2; the land area is 150×10^6 km^2.

My typical British 3-bedroom house has a floor area of 88 m^2. In the USA, the average size of a single-family house is 2330 square feet (216 m^2).

hectare	$= 10^4$ m^2
acre	= 4050 m^2
square mile	= 2.6 km^2
square foot	= 0.093 m^2
square yard	= 0.84 m^2

Table I.5. Areas.

Powers

If we add the suffix "e" to a power, this means that we're explicitly talking about electrical power. So, for example, a power station's output might be 1 GW(e), while it uses chemical power at a rate of 2.5 GW. Similarly the

Land use	area per person (m^2)	percentage
– domestic buildings	30	1.1
– domestic gardens	114	4.3
– other buildings	18	0.66
– roads	60	2.2
– railways	3.6	0.13
– paths	2.9	0.11
– greenspace	2335	87.5
– water	69	2.6
– other land uses	37	1.4
Total	2670	100

Table I.6. Land areas, in England, devoted to different uses. Source: Generalized Land Use Database Statistics for England 2005. [3b7zdf]

1000 BTU per hour	=	0.3 kW	=	7 kWh/d
1 horse power (1 hp or 1 cv or 1 ps)	=	0.75 kW	=	18 kWh/d
		1 kW	=	24 kWh/d

1 therm	=	29.31 kWh
1000 Btu	=	0.2931 kWh
1 MJ	=	0.2778 kWh
1 GJ	=	277.8 kWh
1 toe (ton of oil equivalent)	=	11 630 kWh
1 kcal	=	1.163×10^{-3} kWh

1 kWh	=	0.03412 therms	3412 Btu	3.6 MJ	86×10^{-6} toe	859.7 kcal

Box I.7. How other energy and power units relate to the kilowatt-hour and the kilowatt-hour per day.

suffix "th" may be added to indicate that a quantity of energy is thermal energy. The same suffixes can be added to amounts of energy. "My house uses 2 kWh(e) of electricity per day."

If we add a suffix "p" to a power, this indicates that it's a "peak" power, or capacity. For example, 10 m^2 of panels might have a power of 1 kWp.

1 kWh/d = $\frac{1}{24}$ kW.

1 toe/y = 1.33 kW.

Petrol comes out of a petrol pump at about half a litre per second. So that's 5 kWh per second, or 18 MW.

The power of a Formula One racing car is 560 kW.

UK electricity consumption is 17 kWh per day per person, or 42.5 GW per UK.

"One ton" of air-conditioning = 3.5 kW.

World power consumption

World power consumption is 15 TW. World electricity consumption is 2 TW.

Useful conversion factors

To change TWh per year to GW, divide by 9.
1 kWh/d per person is the same as 2.5 GW per UK, or 22 TWh/y per UK
To change mpg (miles per UK gallon) to km per litre, divide by 3.
At room temperature, $1\,kT = \frac{1}{40}$eV
At room temperature, $1\,kT$ per molecule = 2.5 kJ/mol.

Meter reading

How to convert your gas-meter reading into kilowatt-hours:

- If the meter reads **100s of cubic feet**, take the number of units used, and multiply by **32.32** to get the number of kWh.
- If the meter reads **cubic metres**, take the number of units used, and multiply by **11.42** to get the number of kWh.

	kWh/t-km
inland water	0.083
rail	0.083
truck	0.75
air	2.8
oil pipeline	0.056
gas pipeline	0.47
int'l water container	0.056
int'l water bulk	0.056
int'l water tanker	0.028

Table I.8. Energy intensity of transport modes in the USA. Source: Weber and Matthews (2008).

Calorific values of fuels

Crude oil: 37 MJ/l; 10.3 kWh/l.
Natural gas: 38 MJ/m^3. (Methane has a density of 1.819 kg/m^3.)
1 ton of coal: 29.3 GJ; 8000 kWh.
Fusion energy of ordinary water: 1800 kWh per litre.
See also table 26.14, p199, and table D.3, p284.

Heat capacities

The heat capacity of air is 1 kJ/kg/°C, or 29 J/mol/°C. The density of air is 1.2 kg/m^3. So the heat capacity of air per unit volume is 1.2 kJ/m^3/°C.

Latent heat of vaporization of water: 2257.92 kJ/kg. Water vapour's heat capacity: 1.87 kJ/kg/°C. Water's heat capacity is 4.2 kJ/l/°C.

Steam's density is 0.590 kg/m^3.

Pressure

Atmospheric pressure: 1 bar $\simeq 10^5$ Pa (pascal). Pressure under 1000 m of water: 100 bar. Pressure under 3000 m of water: 300 bar.

Money

I assumed the following exchange rates when discussing money: €1 = $1.26; £1 = $1.85 ; $1 = $1.12 Canadian. These exchange rates were correct in mid-2006.

Greenhouse gas conversion factors

France	83
Sweden	87
Canada	220
Austria	250
Belgium	335
European Union	353
Finland	399
Spain	408
Japan	483
Portugal	525
United Kingdom	580
Luxembourg	590
Germany	601
USA	613
Netherlands	652
Italy	667
Ireland	784
Greece	864
Denmark	881

Figure I.9. Carbon intensity of electricity production (g CO_2 per kWh of electricity).

Fuel type	emissions (g CO_2 per kWh of chemical energy)
natural gas	190
refinery gas	200
ethane	200
LPG	210
jet kerosene	240
petrol	240
gas/diesel oil	250
heavy fuel oil	260
naptha	260
coking coal	300
coal	300
petroleum coke	340

Figure I.10. Emissions associated with fuel combustion. Source: DEFRA's Environmental Reporting Guidelines for Company Reporting on Greenhouse Gas Emissions.

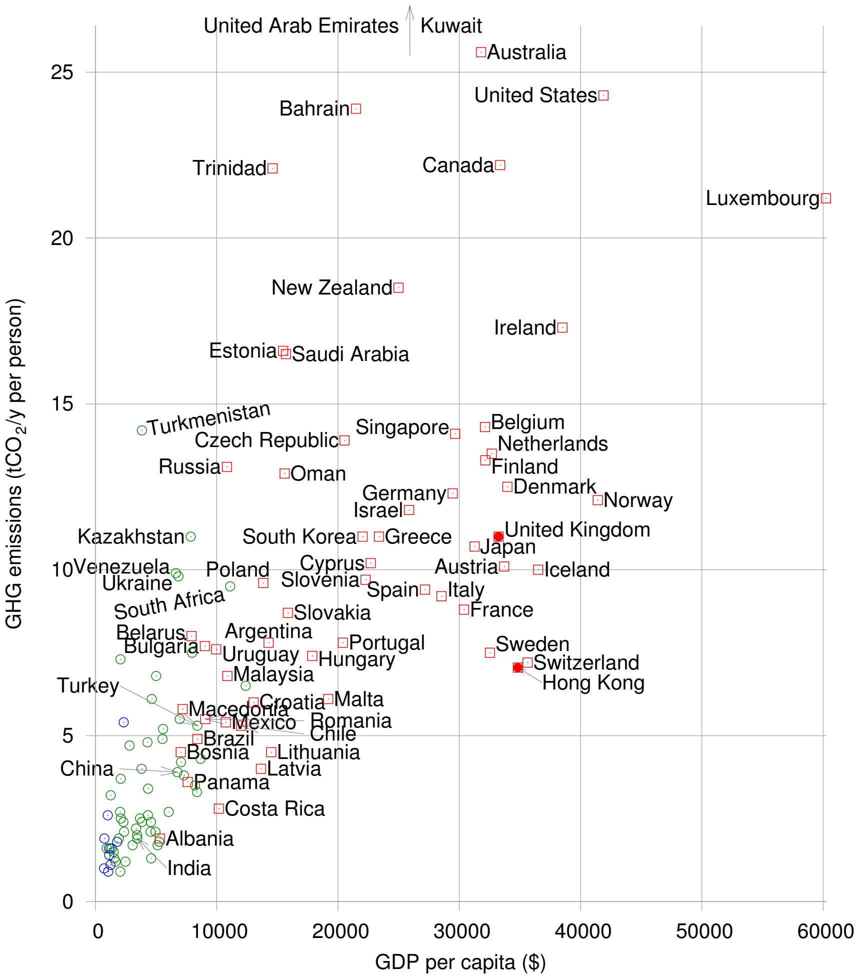

Figure I.11. Greenhouse-gas emissions per capita, versus GDP per capita, in purchasing-power-parity US dollars. Squares show countries having "high human development;" circles, "medium" or "low." See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007. [3av4s9]

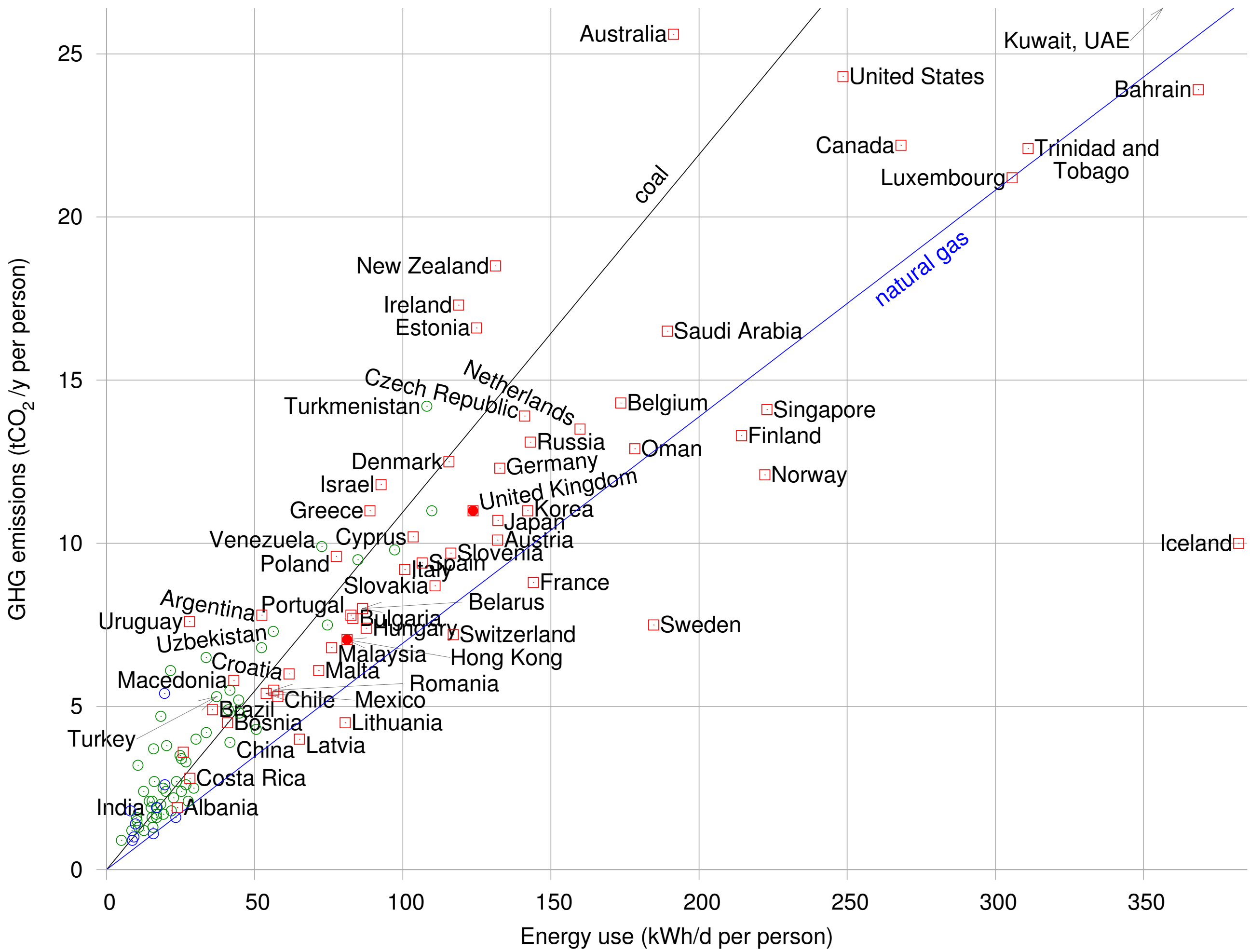

Figure I.12. Greenhouse-gas emissions per capita, versus power consumption per capita. The lines show the emission-intensities of coal and natural gas. Squares show countries having "high human development;" circles, "medium" or "low." See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007.