More on the Units of Energy

Posted by Heading Out on January 19, 2007 - 10:42am
Topic: Miscellaneous
Tags: barrel, bbl, btu, eia, oil, oil prices, peak oil, quad [list all tags]

When we talk about Energy, it is often hard to get a good feel for the quantities that we are talking about. The United States uses about 100 Quads of Energy a year where a Quad is a quadrillion Btu's. When I first saw that, I had to go away and look up how much a Quadrillion was, and could barely remember a British Thermal Unit (Btu) from when I was in school. And given that we are now thinking of using Exajoules instead (a Btu being roughly 1,000 joules), life seems to be getting a little beyond the stretches of my imagination.

Units tend to be something that was originally almost an arbitrary choice. For example, when I want to cook fish, I know that it takes 10 minutes per inch, and so I use the first joint on my forefinger to see how thick the fish is and to decide how long to cook it. (And it works out quite well). When I need to buy something to length, I can get a first sense of how much I need by spreading my palms and touching my thumbs and from one side of one hand to the other side of the other is close enough to a foot. But a Quadrillion (1,000,000,000,000,000 in the US – add 000,000,000 to the end for the British system) is a little hard to visualize. Showing the volume occupied by a quadrillion pennies doesn't really help much. And as for the Btu, well it's the amount of heat required to raise the temperature of 1 lb of water by 1 degree Fahrenheit. Which would be good to know if I could remember how much volume there was in a pound (Oh! Yes there are 8 fluid ounces to a cup). So how can we get a real sense of how much energy we are talking about? After all we measure natural gas in thousands of cubic feet (or meters), coal in tons (or is it tonnes); oil in barrels; while wind, solar, nuclear and hydro usually are given in either billion kilowatt hours a year or in megawatts (though sometimes acre-feet has an impact on hydro). So how do we decide if spending $138 million on a wind farm in New Zealand that will produce 88 megawatts, or one that will generate 132 megawatts in Maine is a better idea that, say, installing an LNG vaporization plant that will produce 400 million cubic feet of natural gas a day in Connecticut. Well to begin with it would help if we could reduce all the different terms to a common comparative base. And so that is what this post is about.

Since this is the Oil Drum, and we have an idea as to how big an oil barrel is (though remember that it is 42 gallons and not 55), I am going to use a barrel of oil as the basic unit for comparison, and will insert a comparison table just a little further down the post.

But you need to bear in mind that not all oil is created equal. There are sweet crudes, and sour crudes, heavy crudes and light ones, and they can all be refined to give different fractions of their volume into a variety of hydrocarbon products. (See Robert's informative post on this). So the number that I use will be an average. But it also helps to remember how powerful this fluid is.

Consider that the average car might weigh 3,500 lb which, with a couple of folk inside could readily get the weight up to two tons. Now if the average mileage it gets is 21 mpg, and lets say it gets this while doing 63 mph, then it takes 20 minutes and 1 gallon of gas to get the car moving those 21 miles. Put another way, in a minute the car will have gone just over a mile and used 0.4 pints of gas, or, in a second it will have used almost a teaspoon of gas, and moved the car and contents some 92 ft. Pretty powerful stuff! And so, as a measure of performance, a barrel of oil will move the average car and family, about 900 miles. (Incidentally at an efficiency of around 1-2% but that will be another story).

In 1954 there were 511,000 oilwells in the United States, with an average production of 12.4 barrels a day (bd). By 2005 the number of wells had dropped to 506,000 with an average production of 10.1 bd. In Europe it is more common to find the amount of oil produced being given in tonnes, thus when a story, such as the restart of oil flows through Belarus comes along it often contains both sets of units, which may make it a little more difficult to understand. Based on a discussion we had in comments, one can multiply the tonnes by 7 to give barrels, so that the tax that Belarus was seeking to apply was some $6.50 a barrel. Alternately when Russian production is reported as 438.7 million tonnes from January to November we divide by 11 and multiply by 12, to convert it to an annual rate, then divide by 50 and get a production rate of 9.57 mbd.

In the same way as oil has a variety of assays – or contents, so also is coal not a simple product and so for this also we use an average. A ton of coal fills about a cubic yard of space (depending on how it is packed). Back in the days of hand-loading coal, a miner might expect to mine up to 20 tons a shift, depending on the conditions. (Remember the song "Load fifteen tons and what do you get?) On the other hand China produced 2.3 billion tons last year. That is the equivalent of about 24.5 million barrels of oil a day (mbd). The Chinese production is about 35% of world production , yet the industry is so inefficient that the average miner will only produce around 321 tons a year (about 1,250 barrels of oil). Very roughly a ton of coal is equivalent to around 4 barrels of oil. In 2005 there were 670 underground, and surface coal mines in the United States and they produced 369,370,807 tons from underground and 765,662,208 tons from surface mines, for a total of 1,135,033,015 tons , the equivalent of 12 mbd.

When one looks at natural gas, the difference between Europe and the United States is reflected in that one measures in cubic meters, and the other in cubic feet. So by normalizing to barrels a day of oil equivalent we can get over that confusion. For example while the Shah Deniz gas field came back into production too late to save Lord Browne's job, it is now producing 3.4 million cubic meters of gas a day. It sounds a lot but is only the equivalent of 16,000 bd – though since that is coming from a single well it is definitely not something to be sneezed at. And going back to that LNG facility in Connecticut. If it plans to vaporize 400 mcf of natural gas a day, that is 0.146 trillion cubic feet (tcf) of natural gas a year, the equivalent of 70,000 bd.

And that brings us to the direct power producers, the wind turbines, hydro-electric power plants and nuclear facilities. And here also you find some confusion between reported production numbers that requires that you know the difference between kilowatts, megawatts and kilowatt hours. There is also an efficiency factor in the conversion of the wind/solar energy/ nuclear pellet to electric power that sometimes can, and sometimes cannot easily be changed. Consider, for example, that a single nuclear pellet in a reactor is about 0.3 inches in diameter and half-an-inch long and yet has the power of 3.5 barrels of oil. Here is not the place to get into a discussion of the varying power demands over the course of a day or year, and the changes in power prices that go with them. But it is necessary to talk just a little about the difference between power and energy.

To start at the beginning a generator (wind turbine, nuclear pellet, solar cell) puts out a certain amount of power. This instant value is generally measured in watts (a kilowatt being 1,000 watts and a megawatt being a million watts, and a gigawatt is a million kilowatts). Thus, to use the example cited, a light bulb might consume 75 watts. If it burns for an hour then it will use 75 watt-hours, or 0.075 kilowatt hours (kwh). But because demand varies, so the size of the power supply that is required must also not only vary, but be able to cope with the largest demand placed on it.

> For instance, a 100 MW rated wind farm is capable of producing 100 MW during peak winds, but will produce much less than its rated amount when winds are light. As a result of these varying wind speeds, over the course of a year a wind farm may only average 30 MW of power production. Similarly, a 1,000 MW coal plant may average 750 MW of production over the course of a year because the plant will shut down for maintenance from time-to-time and the plant operates at less than its rated capability when other power plants can produce power less expensively.

The ratio of a power plant's average production to its rated capability is known as capacity factor. In the previous example, the wind farm would have a 30 percent capacity factor (30 MW average production divided by 100 MW rated capability) and the coal plant would have a 75 percent capacity factor (750 MW average divided by 1,000 MW rated capability). Load factor generally, on the other hand, is calculated by dividing the average load by the peak load over a certain period of time. If the residential load at a utility averaged 5,000 MW over the course of a year and the peak load was 10,000 MW, then the residential customers would be said to have a load factor of 50 percent (5,000 MW average divided by 10,000 MW peak).

Knowing the peak and average demand of a power system is critical to proper planning. The power system must be designed to serve the peak load, in this example 10,000 MW. But the actual load will vary. The load might be 10,000 MW at noon, but only 4,000 MW at midnight, when fewer appliances are operating. The capacity or load factor gives utility planners a sense of this variation. A 40 percent load factor would indicate large variations occur in load, while a 90 percent load factor would indicate little variation. Residential homes tend to have low load factors because people are home and using appliances only during certain hours of the day, while certain industrial customer will have very high load factors because they operate 24 hours a day, 7 days a week.

The amount of electricity consumed by a typical residential household varies dramatically by region of the country. According to 2001 Energy Information Administration (EIA) data, New England residential customers consume the least amount of electricity, averaging 653 kilowatt hours (kWh) of load in a month, while the East South Central region, which includes states such as Georgia and Alabama and Tennessee, consumes nearly double that amount at 1,193 kWh per household.

More detailed energy use for households can be found at the EIA website .

So if we have a power plant that has a maximum operating capacity, for example, of 750 MW and runs at 50% capacity, on average, then it will produce 750,000 x 365 x 24 x 0.5 = 3.3 billion kWh per year, the equivalent of 16,000 bd of oil.

There are other posts on the site, that I will gradually find and incorporate, that discuss such things as wind turbine load factors, but I think I may have given you enough to think about for now.

I will end with a couple of tables for conversions, which I adapted from those given by Stobaugh and Yergin, from their book “Energy Futures.”

Conversions				
1	thousand cu ft	natural gas	0.175	barrels oil
1	ton	coal	3.883	barrels oil
1	thousand kWh	electric power	1.834	barrels oil
1	tonne	oil	7	barrels oil

And for those who, in times when power supplies are questionable, rely on a wood stove. From Wood: An Alternative Source for Home heating (pdf file).

TABLE 3. AVAILABLE HEAT FROM WOOD COMPARED WITH EQUIVALENT AMOUNTS OF OTHER FUELS

Species of Wood	Available Heat[1] Per Cord (Million Btu's)	Iowa Coal (tons)	No. 2 Fuel Oil (gallons)	Nat. Gas (100 cu. ft.)	L.P. Gas (gallons)	Electricity (kilowatt hrs.)
Black locust	14.6	1.46	160	195	216	4,275
Shagbark hickory	14.2	1.42	156	189	210	4,153
White oak	13.1	1.31	144	175	195	3,851
Red oak	12.3	1.23	135	164	182	3,606
White ash	12.1	1.21	133	161	179	3,541
Hard maple	11.9	1.19	130	158	176	3,476
Green ash	11.5	1.15	126	153	170	3,362
Red elm	10.4	1.04	114	139	154	3,052
Sycamore	10.0	1.00	110	133	148	2,929
American elm	10.0	1.00	110	133	148	2,929
Silver maple	9.6	0.96	105	128	142	2,807
Cottonwood	7.9	0.79	87	105	117	2,317
Basswood	6.9	0.69	76	92	102	2,023
Hackberry	10.7	1.07	118	143	159	3,136

[1] Available heat is defined as total heat potential based on the efficiency factor of the stove; 50% efficiency of wood burner is assumed.

[2] Iowa coal has total heat content of 10,000 Btu's per pound; 50% efficiency of hand-fired coal burners yields 5,000 Btu's per pound.

[3] Total heat content is 140,000 Btu's per gallon burned at 65% efficiency yields 91,000 Btu's per gallon.

[4] Total heat content is 100,000 Btu's per 100 cu. ft. burned at 75% efficiency yields 75,000 Btu's per 100 cu. ft.

[5] Total heat content is 90,000 Btu's per gallon, burned at 75% efficiency yields 67,500 Btu's per gallon.

[6] Total heat 3,412 Btu's per kilowatt hour. 100% efficient.

Oh, and for those of you who wondered about the Quad, it is the equivalent of 470,000 bd of oil for a year. And, to make a final point, when the Government are reporting that the ethanol target for 2012 is 7.5 billion gallons , remember that you divide first by 42, which gives 178 million barrels a year, and then you divide by 365 to get 489,000 bd. And so you may initially think that the target is a Quad, but you still have to remember that ethanol has only about 60% of the energy of gasoline, and so the target will be around the equivalent of 300,000 bd of oil. Doesn't quite sound as much, does it ?

The Oil and Gas Journal give the following numbers for US Energy Demand in 2006

Oil 40.6 Quad
Gas 22.6 Quad
Coal 22.8 Quad
Nuclear 8.3 Quad
Hydro etc 6.5 Quad