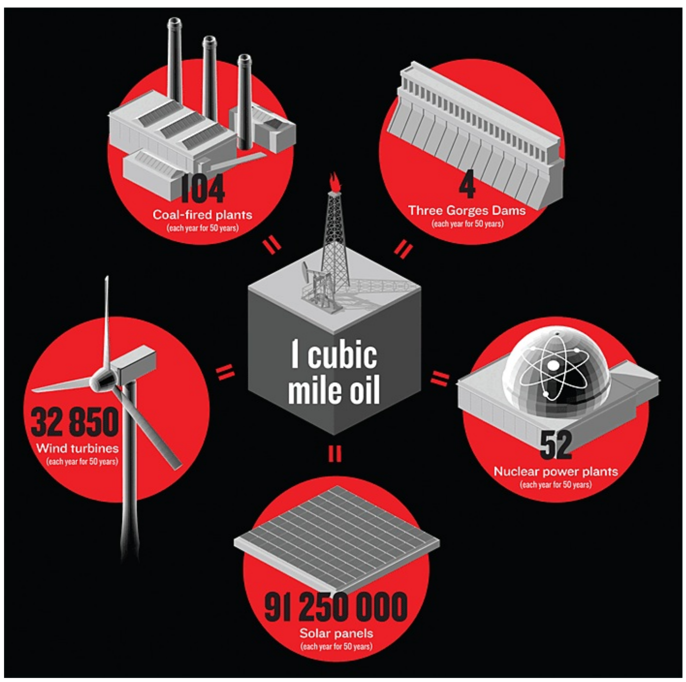
That cubic mile

Posted by Engineer-Poet on February 28, 2007 - 11:50am
Topic: Alternative energy
Tags: efficiency, heat, nuclear, photovoltaics, solar power [list all tags]

A lot's been said lately about how much energy is in a cubic mile of oil. This is roughly the amount the world uses in a year.



Assumptions: The Three Gorges Dam is rated at its full design capacity of 18 gigawatts. A nuclear power plant is postulated to be the equivalent of a 1.1-GW unit at the Diablo Canyon plant in California. A coal plant is one rated at 500 megawatts. A wind turbine is one with a 100-meter blade span, and rated at 1.65 MW. A solar panel is a 2.1-kilowatt system made for home roofs. In comparing categories, bear in mind that the average amount of time that power is produced varies among them, so that total energy obtained is not a simple function of power rating.
src: Joules, BTUs, Quads—Let's Call the Whole Thing Off, IEEE Spectrum, January 2007
Illustration: bryan christie design. Click to enlarge.

Leaving aside some errors (the coal and nuclear numbers are off by about 10% to each other, and the capacity factor of wind turbines should be closer to 30%) the most essential oversight in that equation is elephantine:

It compares oil's *inputs* to the other's *outputs*.

Compared to that, the rest is small potatoes.

According to IEEE Spectrum, a cubic mile of oil has energy equivalent to:

- 4 Three Gorges dams, cranking for 50 years.
- 32850 1.65 megawatt wind turbines, cranking for 50 years (100% capacity factor).
- 91,250,000 2.1 kW solar PV installations, for 50 years.
- 104 500 megawatt coal-fired electric plants, for 50 years.
- 52 1.1 gigawatt nuclear electric plants, for 50 years.

Let's start this analysis over, with these figures:

- A barrel of oil has 6.1 gigajoules (GJ) of chemical energy.
- A cubic mile is 26.2 billion barrels (42 gallons/bbl). (The USA uses about 20.5 million bbl/day, or 7.5 billion barrels/year; this comes to less than a third of a cubic mile annually. World annual consumption is closer to 1.3 cubic miles.)

By this, a cubic mile of oil is even more impressive: $1.60*10^{20}$ joules. That's 5070 gigawatt-years of energy, nearly twice IEEE's estimate. But that's what we put *in*. What do we get *out* of it, and what would it take to replace it?

Ins and outs

Oil gets turned into a bunch of different things, and those uses vary widely in efficiency. If used for heat, oil can be very efficient. Bunker fuel burned in low-speed marine diesels can yield 50% efficiency. But our most important uses of oil are also the least efficient.

Take the average car or light truck. They don't run on crude oil; they require a highly refined fraction known as gasoline. Demands of octane rating, vapor pressure and sulfur and aromatic content increase the losses in the refining process. One source claims 82.9% efficiency from an oil well to a refinery's gasoline output. That cubic mile just got smaller.

But the losses are just starting! The average vehicle is very inefficient, turning just 14.9% of the energy that goes into the tank to work done against air and rolling resistance. The rest is lost in the engine, transmission and brakes. From well to wheels, the total is a pathetic 12.4%. That cubic mile just shrunk by half... in all three dimensions! Diesel is more efficient both at the refining end (87.9%) and the consumption end (35-40% engine efficiency in heavy trucks) but overall throughput is still around 1/3.

If the world followed US patterns (it doesn't, but it's not that far off), refineries would average perhaps 90% efficient. Gasoline would be about 43% of the total energy of the product supplied, distillate (diesel and heating oil) 22%, jet fuel 8.3%. All the rest comes to 27%. If we drop jet fuel as non-essential and add the rest up by efficiency (14.9% gasoline, 40% diesel), the total useful energy comes to 42.2% of the input. Best of all, only 15.2% of that is mechanical work; the rest is heat.

Adding up the end products

If we were going to supply a cubic-mile-of-oil equivalent of heat and work from nuclear plants at 33% thermal efficiency (3.3 GW thermal input, 2.2 GW thermal + 1.1 GW electric output) it would take a lot less. If you cranked them for 50 years, a mere 14 1.1 GW plants could supply 771 GW-years of electricity and another 1540 GW-years of low-grade heat, more than satisfying the requirement of 1370 GW-years of heat from oil. Coal would do about about the same, but it would take 31 500 MW plants to equal the 14 nukes. Wind has no waste heat stream and couldn't do as well (the energy would have to be all electric), but the possibilities for solar are amazing. Solar heat (for space heat) can be collected for very little, sometimes for free with careful design. Supplying 770 GW-years of electricity from solar PV at 25% capacity factor would require only about 40 million 2.1 kW installations; doing a year's worth per year would require about 2 billion 2.1 kW systems, or about 700 watts per capita.

700 watts is about 10 of today's PV panels. The industrial nations could almost afford to give 10 panels to every child at birth, and cost improvements in the pipeline could extend this to much of the world in the next decade or two.

Imagine clean, cheap energy as a birthright. Something to ponder.

Edit: Note that this analysis only considers energy obtained from oil. Weighing this against the total consumption of (especially first-world) humanity leads to inaccurate conclusions; coal, gas, nuclear and hydro sum to considerably more total energy than oil. Ponder and discuss accordingly.

[ED by PG] You may also want to check out Khebab's story called "Getting a Grasp on Oil Production Volumes" which also discusses this topic.