Burning Buried Sunshine

Posted by Dave Cohen on September 27, 2006 - 4:07pm
Topic: Environment/Sustainability
Tags: bioenergy, carbon emissions, climate change, ecological footprint, fossil fuels, jeffrey dukes, mathis wackernagel, overshoot, peat swamp forests [list all tags]

I thought it was time to step far enough away from the myopia induced by current oil prices and, in so doing, provide sufficient space to review the the sustainability of the way we live. The title is taken from Jeffrey Dukes' 2003 paper Burning Buried Sunshine: Human Consumption of Ancient Solar Energy (pdf). Before moving on to Dukes' results, here is a summary of the findings of Mathis Wackernagel, et. al. Tracking the ecological overshoot of the human economy (pdf).

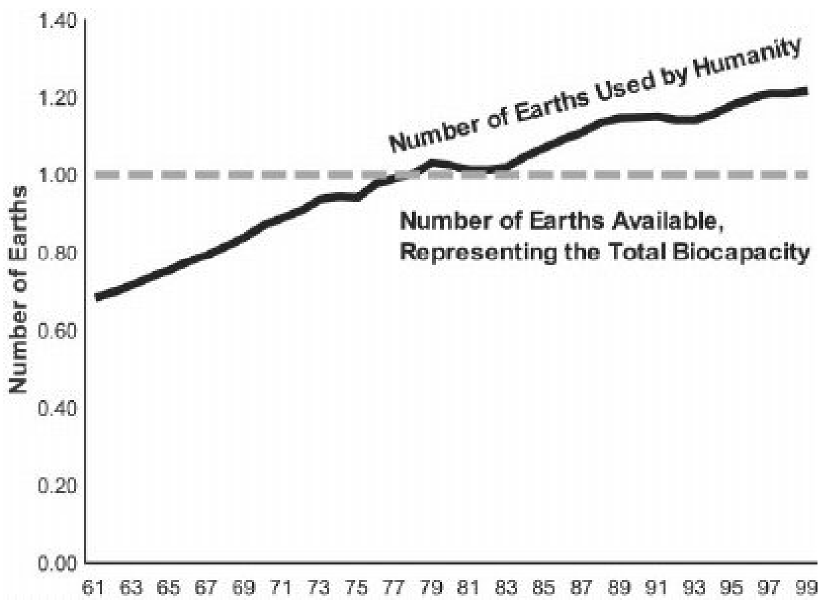
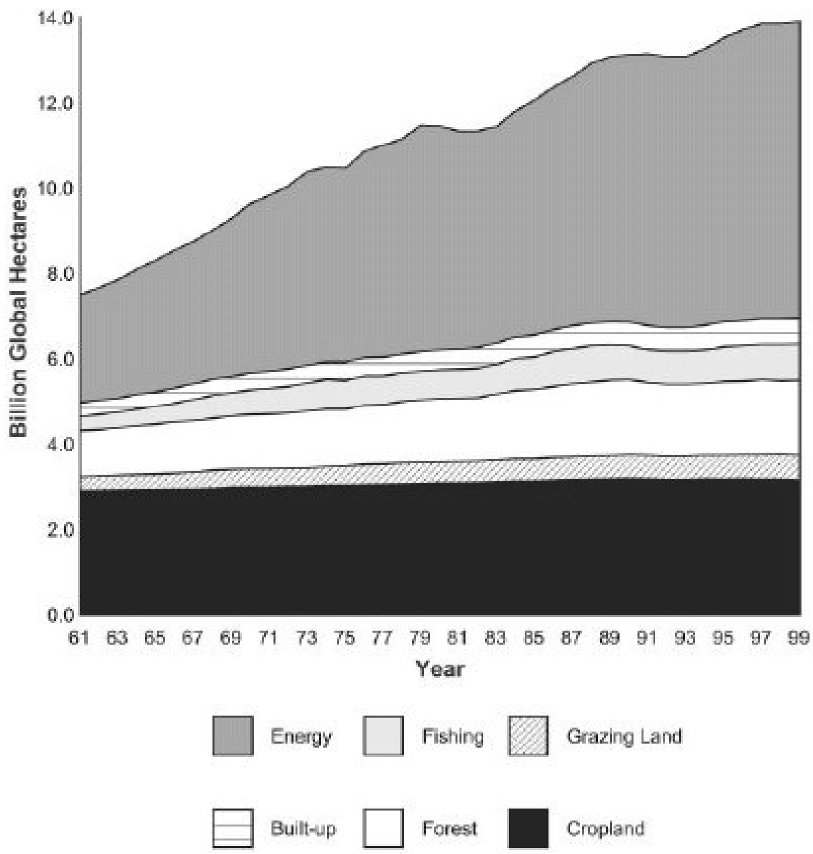


Figure 1

> Sustainability requires living within the regenerative capacity of the biosphere. In an attempt to measure the extent to which humanity satisfies this requirement, we use existing data to translate human demand on the environment into the area required for the production of food and other goods, together with the absorption of wastes. Our accounts indicate that human demand may well have exceeded the biosphere's regenerative capacity since the 1980s. According to this preliminary and exploratory assessment, humanity's load corresponded to 70% of the capacity of the global biosphere in 1961, and grew to 120% in 1999.

Tracking Ecological Overshoot

The purpose of the Wackernagel, et. al. study was to develop an accounting framework by which the "extent of humanity's current demand on the planet's bioproductive capacity" could be measured. Unlike earlier studies like Human Appropriation of the products of photosynthesis by Vitousek, Erhlich, et. al. (1986), which used consumption estimates to calculate humanity's aggregate usage of the Earth's net primary productivity (NPP), Wackernagel took a different approach by calculating humanity's natural capital usage measured in biophysical units. *Figure 2* shows their categories and accounting measured in hectares.



Global ecological demand over time, in global hectares. This graph documents humanity's area demand in six different categories. The six categories are shown on top of each other, demonstrating a total area demand of over 13 billion global hectares in 1999. Global hectares represent biologically productive hectares with global average bioproductivity in that year.
Figure 2

Naturally, the largest and fastest growing component —energy— is of interest here. The approach taken was to calculate the biologically productive area required to sequester enough carbon dioxide (CO_2) to avoid increases in atmospheric levels.

> Because the world's oceans absorb about 35% of the CO_2 emissions from fossil fuel combustion, we account only for the remaining 65%, based on each year's capacity of world-average forests to sequester carbon. This capacity is estimated by taking a weighted average across 26 forest biomes as reported by the IPCC and the FAO.

As they note, there is a lot of uncertainty in this terrestrial carbon sinks methodology because both the land-based and ocean sinks may change in the future due to a number of factors. For background here at TOD, see Stuart Staniford's The Carbon Economy. See my comment note there and also look at The Oceanic Sink for Anthropogenic CO2 if you would like to read further.

For the purposes of this story, the key insight regards the carbon cycle as shown in *Figure 3*.

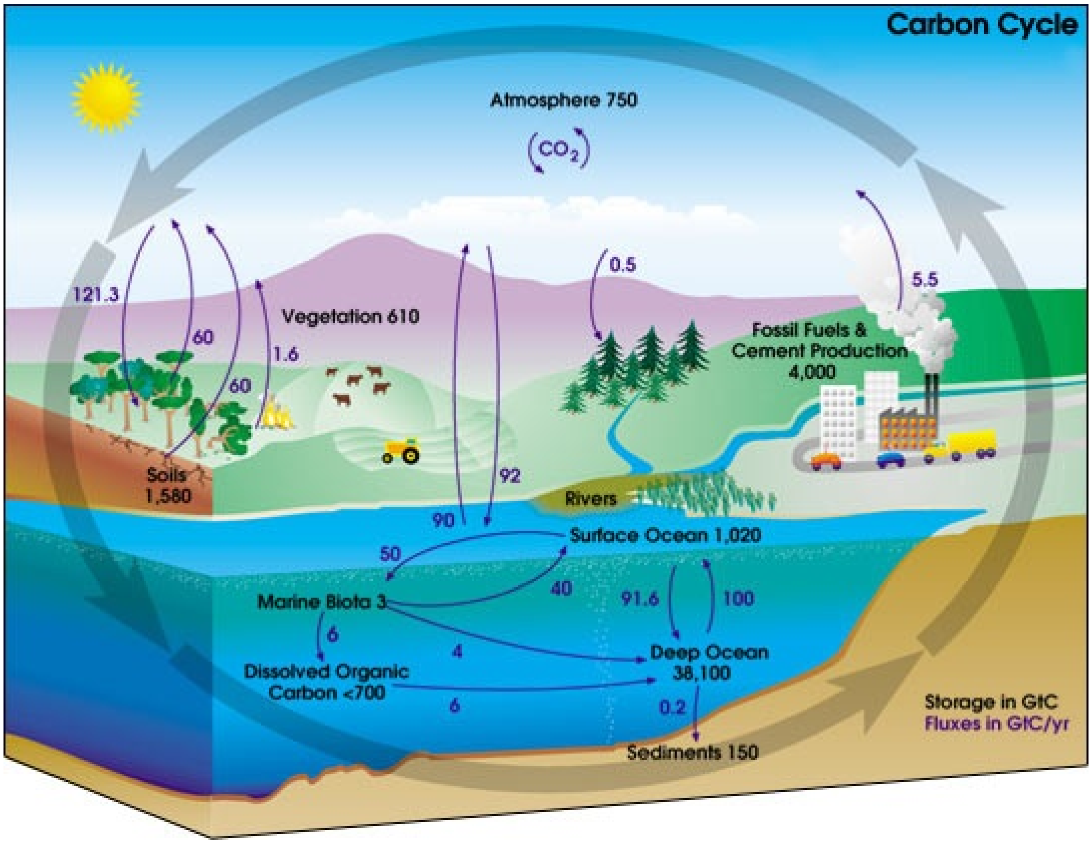


Figure 3 -- click to enlarge

On geological timescales of millions of years, carbon is recycled through the interaction of—among other things—plate tectonics, sedimentation (burial) and volcanism. Plainly, we dig up the fossil fuels, or drill for them, and then burn them for the ancient stored energy they contain. By burning fossil fuels, humankind has altered the current carbon cycle such that we are moving carbon more rapidly from the lithosphere into the atmosphere than would otherwise occur. Currently, CO2 constitutes about 381 million parts per volume (ppmv) in the atmosphere, an increase of over 100 ppmv over pre-industrial times.

Wackernagle et. al. note that an alternative to the sequestration approach would be to calculate the "area requirement for a fossil fuel substitute from biomass, using current technology [which] leads to similar or even larger area demands [than the sequestration approach shown in *Figure 2*]." Jeffrey Dukes believes that the "ecological footprint" analysis they use is inadequate, saying that "true analyses of sustainability must take into account the land or NPP needed to replace the stored [fossil fuel] energy that we use." So, that is what he set out to do.

Burning Buried Sunshine

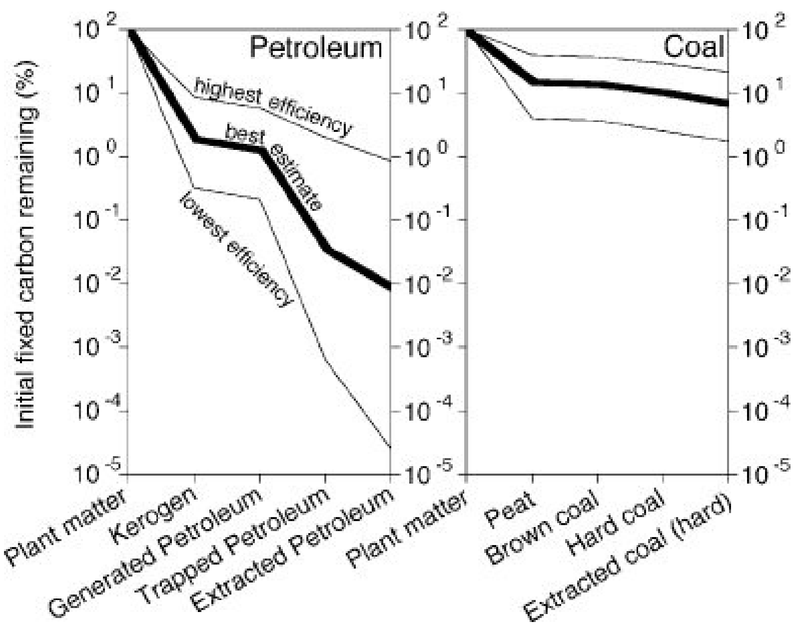
To understand Dukes' results, it is necessary to understand his methodology.

Here, I have compiled data on: (1) the proportion of fossil fuel reserves derived from different environments (i.e., terrestrial vs. marine vs. lacustrine), (2) the efficiency with which photosynthetic organisms are converted to peat or carbonrich sediment in these environments, (3) the efficiency with which organic deposits were converted to fossil fuels, and (4) the efficiency with which we are able to retrieve fossil fuels from near the earth's surface. From these data, I calculate the amount of paleoproductivity that was needed to create fossil fuels. I also estimate the amount of solar energy consumed by humans in the form of fossil fuels, compare the solar efficiency of fossil fuels to that of more modern sources of solar-derived energy, and estimate the minimum amount of modern photosynthetic product necessary to replace fossil fuel energy.

In this paper, a **preservation factor** (PF) is defined as the fraction of carbon that remains at the end of a transition from one fossil fuel precursor to the next, such as that from plant matter to peat, on the path to coal formation. A **recovery factor** (RF) is defined as the proportion of original photosynthetic product recovered as fossil fuel. Recovery factors are the product of the PFs of each transition and additional terms for extraction efficiency (for instance, the fraction of existing coal that can be mined from deposits given today's economic and technological setting).

Dukes then calculates the RF of NPP for both coal and petroleum. Both of these sections of his paper are highly recommended because—aside from telling us how Dukes made his calculations—they provide excellent detail about the geological settings and processes by which fossil fuels have been created "for our use" during the Phanerozoic Eon that started with the Cambrian Explosion about 543 million years ago.

As it turns out, the RF for both is quite small as you can see in *Figure 4*. In moving from ancient buried plant matter to final extraction, almost all of the original carbon is lost. For oil, the RF = .09%, for gas, the RF = .08%. For coal the RF = 9%. So, the whole process, especially for oil & natural gas, is terribly inefficient.



Best estimate (thick line) and high and low limits (thin lines) for the percent of photosynthetically fixed carbon retained during fuel generation and extraction. The final value in each panel is

the equivalent of a recovery factor (RF) for the fuel type. The actual RF for coal varies slightly from the value in the figure, because both brown coal and hard coal are extracted from the earth.
Figure 4

Dukes' section 5, *Applications of the Recovery Factors*, is the "fun facts" part of his paper.

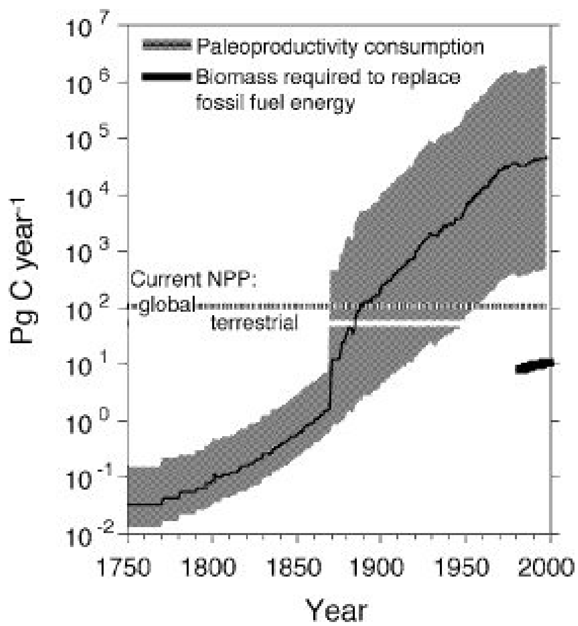
1. The RF for oil suggests that 89 metric tons of ancient plant matter were required to create 1 U.S. Gallon [3.8 L] of gasoline.

2. RFs were used to estimate the amount of ancient photosynthetic product consumed annually in the form of fossil fuels. Approximately 44 Eg (44 × 10^18 grams) of photosynthetic product carbon were necessary to generate the fossil fuels burned in the reference year 1997. This is equivalent to 422 times the net amount of carbon that is fixed globally each year, or 73 times the global standing stock of carbon in vegetation.

3. Paleoproductivity use over time (shown in *Figure 5* below) suggests that societal consumption of this resource has exceeded the current rate of global carbon fixation since 1888. *Cumulative* paleoproductivity consumption from 1751 to 1998 exceeds 1.4 × 103 Eg of carbon (as above), which is more than 13,300 years' worth of global NPP.

Figure 5 shows the human consumption of paleoproductivity (in petragrams (Pg) of carbon per year, where

1 teragram (Tg) Carbon = 10^12 grams
1 petragram (Pg) Carbon = 10^15 grams
1 gigatonne (Gt) Carbon = 10^9 tonnes
1 megatonne (Mt) Carbon = 10^6 tonnes
1 petragram Carbon = 1 gigatonnes Carbon
1 teragram Carbon = 1 megatonnes Carbon



Don't miss the thick line (lower right) -- Figure 5

*Paleo*consumption refers to the amount of ancient NPP (photosynthetically fixed carbon) that was required to generate the fossil fuels used annually between 1751 and 1998, where the thin dark line is the best estimate and the grey space is the high & low error limits. The horizontal bars represent estimates for the current annual NPP (terrestrial excludes the oceans). The **thick line**, which starts in 1980, represents Dukes' "conservative estimate of the amount of biomass that would be consumed if fossil fuel energy sources were replaced with modern biofuels." Also, "the onset of oil consumption in 1870 causes the jump in the high limit and best estimate [the thin, dark line, from 0 to 1] for paleoproductivity consumption" because of the large unit of measurement used.

The University of Utah 2003 press release focused on results #1 through #3 above and some other calculations made by Dukes.

> "Can you imagine loading 40 acres worth of wheat - stalks, roots and all - into the tank of your car or SUV every 20 miles?" asks ecologist Jeff Dukes...
>
> Dukes then divided the 1997 fossil fuel use equivalent of 7.1 trillion kilograms of carbon in plant matter by 31.6 trillion kilograms now available in plants. He found we would need to harvest 22 percent of all land plants just to equal the fossil fuel energy used in 1997 - about a 50 percent increase over the amount of plants now removed or paved over each year.
>
> "Relying totally on biomass for our power - using crop residues and quick-growing forests as fuel sources - would force us to dedicate a huge part of the landscape to growing these fuels. It would have major environmental consequences. We would have to choose between our rain forests and our vehicles and appliances. Biomass burning can be part of the solution if we use agricultural wastes, but other technologies have to be a major part of the solution as well - things like wind and solar power." [Dukes said]

These shocking results bring home the meaning of the word *sustainability*. They also allow us to understand the meaning of studies on transportation biofuels like Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels from the University of Minnesota (PNAS, July 25, 2006. vol. 103, no. 30, pp. 11206-11210).

> Relative to the fossil fuels they displace, greenhouse gas emissions are reduced 12% by the production and combustion of ethanol [from corn] and 41% by biodiesel [from soybeans]. Biodiesel also releases less air pollutants per net energy gain than ethanol. These advantages of biodiesel over ethanol come from lower agricultural inputs and more efficient conversion of feedstocks to fuel. Neither biofuel can replace much petroleum without impacting food supplies. Even dedicating all U.S. corn and soybean production to biofuels would meet only 12% of gasoline demand and 6% of diesel demand.

All such study results follow in the larger sense from Dukes' analysis.

The Fate of Recently Buried Sunshine

It should not surprise anyone that the geological processes leading to fossil fuels creation continue up to the present. However, the word "recent" does not mean "last week" or even a hundred years ago; rather, it refers to peat formation over the entire course of the Holocene—10,000 radiocarbon years, about 11,430 ± 130 calendar years before the present (BP)— and the upper Pleistocene (from 1.81 million years BP up to the Holocene). Unfortunately, this peat is not staying buried.

Dukes makes the standard assumption that much of the Earth's coal accumulated in peat swamp forests like those in Indonesia and Malaysia.

A "blackwater" peat swamp forest

Peat is a precursor to coal. Given time, pressure and heat, peat becomes brown coal—lignite or sub-bituminous. Eventually, bituminous or anthracite hard coal is created. See Dukes' article for the details. However, these peat swamp forests have been burning in recent years, releasing "million of tons of harmful greenhouse gases into the atmosphere.".

> Fires occur often during the dry season on the South East Asian island of Borneo, but it isn't only the forests that burn. Lowland tropical peat swamps are formed from layers of woody debris too waterlogged to fully decompose. *Slowly deposited over thousands of years, the carbon-rich peat strata have been known to reach a thickness of up to 20 metres.*
>
> By rights these humid peat swamps shouldn't be vulnerable to flame but during the last couple of decades *the Indonesian government started draining them for conversion into agricultural land.* In an unfortunate side effect the dried-up peat swamps are turned into tinderboxes - and once a peat fire begins smouldering it is almost impossible to put out.

Aside from human destruction of the peat, there is an observation concerning how long ago the released carbon (or methane) was buried. The take home message, discussed in relation to melting permafrost, is summarized here:

> The age of soil exposed by melting permafrost has an important impact on the release of carbon dioxide and methane and helps determine possible climate changes. If permafrost thawing exposes relatively young peat, its carbon would have been sequestered fairly recently and its release will result in little or no net increase to the world's atmospheric carbon load (O'Hanlon, 2005). However, *if old peat is also exposed and then decomposes, the carbon produced will be similar to the emissions from burning fossil fuels, releasing carbon that has been stored away from the atmosphere for millions of years.*

Similar remarks apply to the Southeast Asia's peat swamp forests. Although the word "old" is not defined in the text above, the insight is clear enough. For example, in the 19th century, particularly between 1830 and 1880, the forests of New England were cleared for agriculture. Ignoring the complex arguments concerning the overall effects on emissions of landuse changes, the 20th century reforestation of New England might be viewed as offsetting any stored carbon lost when the trees were cut down. However, if the carbon was buried thousands of years ago, no such argument can be made.

The peatlands situation in the Arctic, particularly Western Siberia, is potentially worse than the destruction of Indonesia's peat swamp forests. In Climate warning as Siberia melts, we learn that

- Western Siberia, an area the size of France and Germany combined, has warmed by 3°C in the last 40 years, resulting in rapid melting of the world's largest peat bog.
- The peat bogs formed approximately 11,000 years ago at the end of the last Ice Age.
- The West Siberian region contains about 70 gigatonnes of methane, about 1/4th of all the methane stored on the world's land surface. "If the bogs dry out as they warm, the methane will oxidise and escape into the air as carbon dioxide. But if the bogs remain wet, as is the case in western Siberia today, then the methane will be released straight into the atmosphere. Methane is 20 times as potent a greenhouse gas as carbon dioxide."

There is an ongoing argument among scientists, summarized in this International Polar Year proposal, over whether new plant growth in the warming terrestrial region will replace or even increase NPP there. Thus, more carbon would be stored than is lost from the initial burst of decomposition & respiration in Arctic permafrost and peatlands in response to higher mean surface temperatures in the region. However, *prima facie*, no increase in biomass and therefore annual NPP in the Arctic can offset the loss of ancient carbon which has been accumulating in peatlands since they were established between 9.5 and 11 thousand years ago—a total of 70 gigatonnes representing ~26% of *all terrestrial carbon* formed since the Last Glacial Maximum. This is just the kind of observation Dukes makes in his study.

Quantifiying, Understanding and Managing the Carbon Cycle in the Next Decades (pdf) states that "a preliminary estimate suggests that up to 100 PgC of CO2 equivalent could be released to the atmosphere from wetlands and peatlands over the next 100 years." The estimate includes both the Arctic and the tropical peatlands. 100 petragrams = 100 gigatonnes. CO2 emissions from human burning of fossil fuels amount to approximately 7 gigatonnes per year. So, current studies indicate that the fate of sequestered carbon in Arctic and tropical peat is ultimately release into the Earth's atmosphere and oceans.

The essay has attempted to describe the bigger picture concerning the sustainability of the way we live on the Earth. It seems obvious that as demand for fossil fuels increases, population increases, stress on natural resources increases and the amount of greenhouse gas emissions increases, that eventually something's gotta give. And now, a final thought.

The Planet Earth has been shot.
Round up the usual suspects