

Our Finite World

Providing a wide view of what may be ahead

The Long-Term Tie Between Energy Supply, Population, and the Economy

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The tie between energy supply, population, and the economy goes back to the hunter-gatherer period. Hunter-gatherers managed to multiply their population at least 4-fold, and perhaps by as much as 25-fold, by using energy techniques which allowed them to expand their territory from central Africa to virtually the whole world, including the Americas and Australia.

The agricultural revolution starting about 7,000 or 8,000 BCE was next big change, multiplying population more than 50-fold. The big breakthrough here was the domestication of grains, which allowed food to be stored for winter, and transported more easily.

The next major breakthrough was the industrial revolution using coal. Even before this, there were major energy advances, particularly using peat in Netherlands and early use of coal in England. These advances allowed the world's population to grow more than four-fold between the year 1 CE and 1820 CE. Between 1820 and the present, population has grown approximately seven-fold.

Approximate World Annual Growth Rates

	<u>Population</u>	<u>Energy</u>	<u>GDP</u>
7,000 BCE-1	0.06%		
1 - 1000	0.02%		0.01%
1000-1500	0.10%		0.14%
1500-1600	0.24%		0.29%
1600-1700	0.08%		0.11%
1700-1820	0.46%		0.52%
1820-1870	0.41%	0.63%	0.94%
1870-1900	0.68%	1.16%	1.93%
1900-1920	0.88%	2.01%	3.06%
1920-1940	1.06%	1.18%	1.12%
1940-1950	0.95%	2.24%	1.71%
1950-1960	1.87%	3.85%	4.68%
1960-1970	1.95%	5.15%	5.02%
1970-1980	1.86%	2.60%	3.82%
1980-1990	1.73%	1.80%	3.08%
1990-2000	1.44%	1.34%	3.06%
2000-2010	1.18%	2.33%	3.51%

Table 1. Population growth rate prior to the year 1 C. E. based on McEvedy & Jones, "Atlas of World Population History", 1978; later population as well as GDP based on Angus Madison estimates; energy growth estimates are based on estimates by Vaclav Smil in Energy Transitions: History Requirements, and Prospects, adjusted by recent information from BP's 2012 Statistical Review of World Energy.

When we look at the situation on a year-by-year basis (Table 1), we see that on a yearly average basis, growth has been by far the greatest since 1820, which is the time since the widespread use of fossil fuels. We also see that economic growth seems to proceed only slightly faster than population growth up until 1820. After 1820,

there is a much wider “gap” between energy growth and GDP growth, suggesting that the widespread use of fossil fuels has allowed a rising standard of living.

The rise in population growth and GDP growth is significantly higher in the period since World War II than it was in the period prior to that time. This is the period during which growth in which oil consumption had a significant impact on the economy. Oil greatly improved transportation and also enabled much greater agricultural output. An indirect result was more world trade, which enabled production of goods needing inputs around the world, such as computers.

When a person looks back over history, the impression one gets is that the economy is a system that transforms resources, especially energy, into food and other goods that people need. As these goods become available, population grows. The more energy is consumed, the more the economy grows, and the faster world population grows. When little energy is added, economic growth proceeds slowly, and population growth is low.

Economists seem to be of the view that GDP growth gives rise to growth in energy products, and not the other way around. This is a rather strange view, in light of the long tie between energy and the economy, and in light of the apparent causal relationship. With a sufficiently narrow, short-term view, perhaps the view of economists can be supported, but over the longer run it is hard to see how this view can be maintained.

Energy and the Hunter-Gatherer Period

Humans, (or more accurately, predecessor species to humans), first arose in central Africa, a place where energy from the sun is greatest, water is abundant, and biological diversity is among the greatest. This setting allowed predecessor species a wide range of food supplies, easy access to water, and little worry about being cold. Originally, predecessor species most likely had fur, lived in trees, and ate a primarily vegetarian diet, like most primates today. The total population varied, but with the limited area in which pre-humans lived, probably did not exceed 1,000,000, and may have been as little as 70,000 ([McEvedy](#)).

Man’s main source of energy is of course food. In order to expand man’s range, it was necessary to find ways to obtain adequate food supply in less hospitable environments. These same techniques would also be helpful in countering changing climate and in mitigating deficiencies of man’s evolution, such as lack of hair to keep warm, limited transportation possibilities, and poor ability to attack large predators. The way man seems to have tackled all of these other issues is by figuring out ways to **harness outside energy** for his own use. See also my previous post, [Humans Seem to Need External Energy](#).

The earliest breakthrough seems to be the development of **man’s ability to control fire**, at least 1 million years ago ([Berna](#)). The ability to cook food came a very long time ago as well, although the exact date remains uncertain. A diet that includes cook food has a number of advantages: it reduces chewing time from roughly half of daily activities to as little as 5% of daily activities, freeing up time for other activities ([Organ](#)); it allows a wider range of foods, since some foods *must* be cooked; it allows better absorption of nutrients of food that is eaten; it allows smaller tooth and gut sizes, freeing up energy that could be used for brain development ([Wrangham](#)).

There were other advantages of fire besides the ability to cook: it also allowed early humans to keep warm, expanding their range in that way; it gave them an advantage in warding off predators, since humans could hurl

fiery logs at them; and it extended day into night, since fire brought with it light. The wood or leaves with which early man made fire could be considered man's first *external* source of energy.

As man began to have additional time available that was not devoted to gathering food and eating, he could put more of his own energy into other projects, such as hunting animals for food, making more advanced tools, and creating clothing. We talk about objects such as tools and clothing that are created using energy (any type of energy, from humans or from fuel), as having **embedded energy** in them, since the energy used to make them has long-term benefit. One surprising early use of embedded energy appears to have been making seaworthy boats that allowed humans to populate Australia over 40,000 years ago ([Diamond](#)).

The use of [dogs for hunting](#) in Europe at least 32,000 years ago was another way early humans were able to extend their range ([Shipman](#)). Neanderthal populations, living in the same area in close to the same time-period did not use dogs, and died out.

With the expanded territory, the number of humans increased to 4 million ([McEvedy](#)) by the beginning of agriculture (about 7,000 or 8,000 BCE). If population reached 4 million, this would represent roughly a 25-fold increase, assuming a base population of 150,000. Such an increase might be expected simply based on the expanded habitat of humans. This growth likely took place over more than 500,000 years, so was less than 0.01% per year.

Beginning of Agriculture – 7,000 BCE to 1 CE

Relative to the slow growth in the hunter-gatherer period, populations grew much more quickly (0.06% per year according to Table 1) during the Beginning of Agriculture.

One key problem that was solved with the beginning of the agricultural was, **How can you store food until you need it?** This was partly solved by the domestication of grains, which stored very well, and was “energy dense” so it could be transported well. If food were limited to green produce, like cabbage and spinach, it would not keep well, and a huge volume would be required if it were to be transported.

The domestication of animals was another way that food could be stored until it was needed, this time “on the hoof”. With the storage issue solved, it was possible to live in settled communities, rather than needing to keep moving to locations where food happened to be available, season by season. The domestication of animals had other benefits, including being able to use animals to transport goods, and being able to use them to plow fields.

The ability to grow animals and crops of one's own choosing permitted a vast increase the amount of food (and thus energy for people) that would grow on a given plot of land. According to David Montgomery in [Dirt: The Erosion of Civilization](#), the amount of land needed to feed one person was

- Hunting and gathering: 20 to 100 hectares (50 to 250 acres) per person
- Slash and burn agriculture: 2 to 10 hectares (5 to 25 acres) per person
- Mesopotamian floodplain farming: 0.5 to 1.5 hectares (1.2 to 3.7 acres) per person

Thus, a shift to agriculture would seem to allow a something like a 50-fold increase in population, and would pretty much explain the 56-fold increase that took place between from 4 million in 7,000 BCE, to 226 million at

1 CE.

Other energy advances during this period included the use of irrigation, wind-powered ships, metal coins, and the early use of iron tools ([Diamond](#)) ([Ponting](#)). With these advances, trade was possible, and this trade enabled the creation of goods that could not be made without trade. For example, copper and tin are not generally mined in the same location, but with the use of trade, they could be combined to form bronze.

In spite of these advances, the standard of living declined when man moved to agriculture. Hunter-gatherers were already running into limits because they had killed off some of the game species ([McGlone](#)) ([Diamond](#)). While agriculture allowed a larger population, the health of individual members was much worse. The average height of men dropped by 6.2 inches, and the median life span of men dropped from 35.4 years to 33.1 years, according to Spencer Wells in [Pandora's Seed: The Unforeseen Cost of Civilization](#).

Deforestation rapidly became a common occurrence, as population expanded. [Chew](#) lists 40 areas around the world showing deforestation before the year 1, many as early as 4000 BCE. [Montgomery](#) notes that when the Israelites reached the promised land, the better cropland in the valleys was already occupied. In Joshua 17:14-18, Joshua instructs descendants of Joseph to clear as much of the forested land in the hill country as they wish, so they will have a place for their families to live.

Energy, Population, and GDP: Year 1 to 1820

Table 1 shows that during the period 1 to 1000, both population and economic output were very low (population, 0.02% per year; GDP, 0.01% per year). During this period, and as well as in the early agricultural period (between 7,000 BCE and 1 CE), there was a tendency of civilizations that had been expanding to collapse, holding the world's overall population growth level down. There were several reasons for collapses of well-established societies, including (1) soil erosion and other loss of soil fertility, as people cut down trees for agriculture and for use in metal-making, tilled soil, and used irrigation ([Montgomery](#)) ([Chew](#)), (2) increasingly complex societies needed increasing energy to support themselves, but such energy tended not to be available ([Tainter](#)), (3) contagious diseases, often caught from farm animals, passed from person to person because of population density ([Diamond](#)), and (4) there were repeated instances of climate change and natural disturbances, such as volcanoes ([Chew](#)).

Even after 1000 CE, growth was limited, due to continued influence of the above types of factors. In most countries, the vast majority of the population continued to live on the edge of starvation up until the last two centuries ([Ponting](#)). Most growth came from expanded acreage for farming.

There were exceptions, however, and these were where growth of population and GDP was greatest.

Netherlands. [Kris De Decker](#) writes about the growing use of peat for energy in Netherlands starting in the 1100s and continuing until 1700. Peat is partially carbonized plant material that forms in bogs over hundreds of years. It can be mined and burned for processes that require heat energy, such as making glass or ceramics and for baking bread. Because it takes hundreds of years to be formed, mining exhausts it. Mining also causes ecological damage. The availability of peat for fuel was important, however, because there was a serious shortage of wood at that time, because of deforestation due to the pressures of agriculture and the making of metals.

Wind was also important in Holland during the same period. It produced primarily a different kind of energy than peat; it produced kinetic (or mechanical) energy. This energy was used for a variety of processes, including polishing glass, sawing wood, and paper production ([De Decker](#)). Measured as heat energy (which is the way energy comparisons are usually made), wind output would have been considerably less than the heat energy from peat during this time period.

[Maddison](#) shows population in Netherlands growing from 300,000 in the year 1000 to 950,000 in 1500; 1,500,000 in 1600 and 1,900,000 in 1700, implying average annual population growth rates of 0.23%, 0.46%, and 0.24% during the three periods, compared to world average annual increases of 0.10%, 0.24%, and 0.08% during the same three periods. Netherlands' GDP increased at more than double the world rates during these three periods (Netherlands: 0.35%, 1.06%, and 0.67%; world: 0.14%, 0.29%, and 0.11%.)

England. We also have information on early fuel use in England (Wigley).

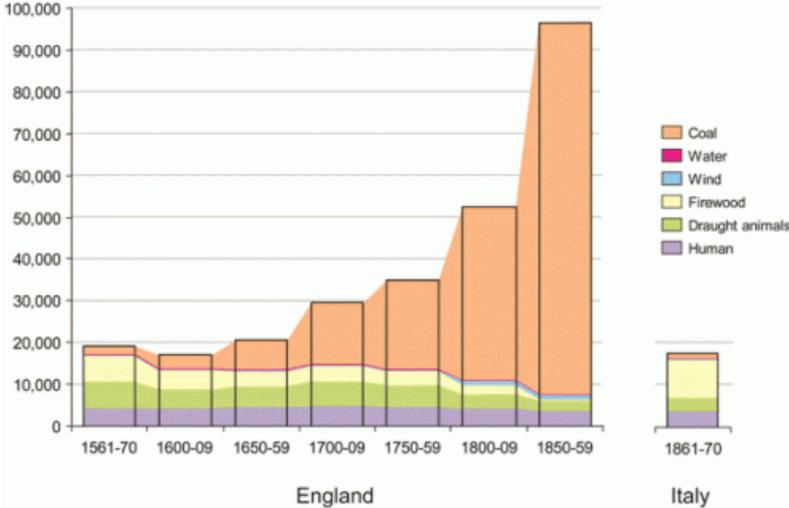


Figure 1. Annual energy consumption per head (megajoules) in England and Wales 1561-70 to 1850-9 and in Italy 1861-70. Figure by [Wrigley](#).

Here, we see that coal use began as early as 1561. To a significant extent coal replaced fire wood, since wood was in short supply due to deforestation. Coal was used to provide heat energy, until after the invention of the first commercially successful steam engine in 1712 ([Wikipedia](#)), after which it could provide either heat or mechanical energy. Wind and water were also used to provide mechanical energy, but their quantities remain very small compared to coal energy, draft animal energy, and even energy consumed in the form of food by humans.

[Maddison](#) shows population and GDP statistics for the United Kingdom (not England by itself). Again, we see a pattern similar to Netherlands, with UK population and GDP growth surpassing world population and GDP growth, since it was a world leader in adopting coal technology. (For the three periods 1500-1600, 1600-1700, and 1700-1820, the corresponding numbers are Population UK: 0.45%, 0.33%, 0.76%; Population World: 0.24%, 0.08%, 0.46%; GDP UK: 0.76%, 0.58%, 1.02%; GDP World: 0.29%, 0.11%, 0.52%.)

Growth “Lull” during 1600s. Table 1 shows that both population growth and GDP growth were lower during the 1600s. This period matches up with some views of when the [Little Ice Age](#) (a period with colder weather) had the greatest impact.

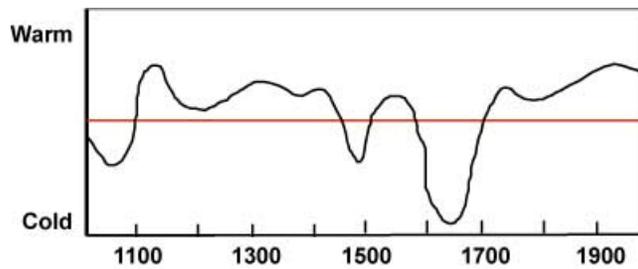


Figure 2. Winter Severity in Europe, 1000 to 1900. Note period of cold weather in 1600s. Figure from [Environmental History Resources](#). Figure based on [Lamb 1969 / Schneider and Mass 1975](#).

If the weather was colder, crops would likely not have grown as well. More wood would be needed for fuel, leaving less for other purposes, such as making metals. Countries might even been more vulnerable to outside invaders, if they were poorer and could not properly pay and feed a large army.

Coal Age for the World – 1820 to 1920 (and continuing)

When the age of coal arrived, the world had two major needs:

1. A heat-producing fuel, so that there would not be such a problem with deforestation, if people wanted to keep warm, create metal products, and make other products that required heat, such as glass.
2. As a transportation fuel, so that walking, using horses, and boats would not be the major choices. This severely limited trade.

When coal arrived, it was rapidly accepted, because it helped greatly with the first of these—the need for a heat-producing fuel. People were willing to put up with the fact that it was polluting, especially in the highly populated parts of the world where wood shortages were a problem. With the availability of coal, it became possible to greatly increase the amount of metal produced, making possible the production of consumer goods of many kinds.

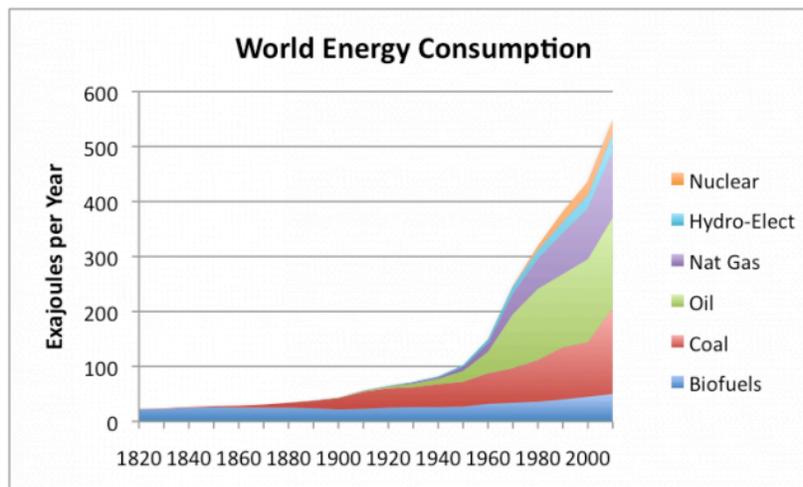


Figure 3. World Energy Consumption by Source, based on Vaclav Smil estimates from *Energy Transitions: History, Requirements and Prospects* and together with BP Statistical Data on 01965 and subsequent

Between 1820 and 1920, which is the period when coal came into widespread use, the world's use of energy

approximately tripled (Figure 3). The large increases in other fuels later dwarf this increase, but the use of coal was very significant for the economy. Table 1 at the top of this post shows a fairly consistent rise in GDP growth as coal was added to the energy mix in the 1820 to 1920 period.

With the invention of first commercially successful steam engine in 1712 ([Wikipedia](#)), coal could also be used for processes that required mechanical energy, such as milling grain, running a cotton gin, or weaving cloth. It also helped as a transportation fuel, in that it could power a railroad train or steam boat. Thus, it did help with the second major energy need noted above. It was not very suitable for airplanes or for private passenger cars, though.

One invention that was made possible by the availability of coal was the widespread use of electricity. Without coal (or oil), it would never have been possible to make all of the transmission lines. Hydroelectric power of the type we use today was also made possible by the availability of coal, since it was possible to create and transport the metal parts needed. The first meaningful amounts of hydroelectric power appeared between 1870 and 1880, according to the data used in Figure 3.

Agriculture was helped by the availability of coal, mostly through the indirect impacts of more/better metal being available, more ease in working with metals, improved transportation, and later, the availability of electricity. According to a [document of the US Department of Census](#), changes were made which allowed more work to be done by horses instead of humans. New devices such as steel plows and reapers and hay rakes were manufactured, which could be pulled by horses. Later, many devices run by electricity were added, such as milking machines. [Barbed-wire fence](#) allowed the West to become cropland, instead one large unfenced range.

Between 1850 and 1930, the percentage of workers in agriculture in the US dropped from about [65% of the workforce to about 22%](#). With such a large drop in agricultural workers, rising employment in other parts of the economy became possible, assuming there were enough jobs available. If not, it is easy to see how the Depression might have originated.

If we look at the coal data included in Figure 3 by itself, we see that the use of coal use has never stopped growing. In fact, its use has been growing more rapidly in recent years:

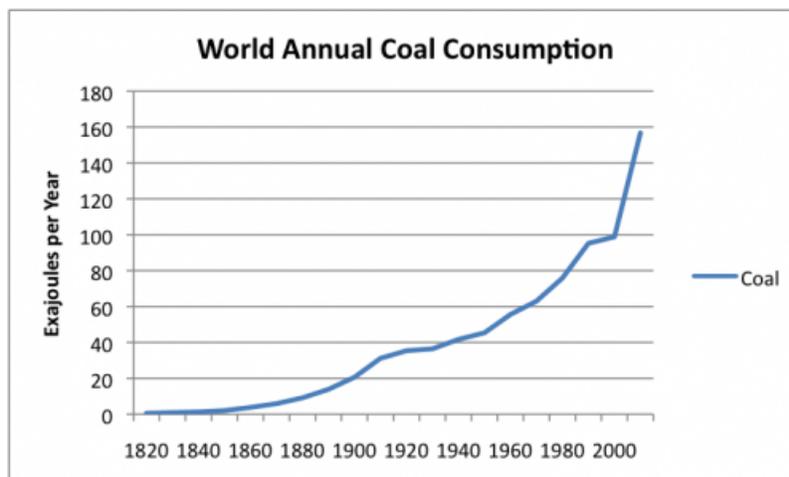


Figure 4. World annual coal consumption, based on same data used in Figure 3. (Vaclav Smil /BP Statistical Review of World Energy)

The big reason for the growth in coal consumption is that it is cheap, especially compared to oil and in most countries, natural gas. China and other developing countries have been using coal for electricity production, to smelt iron, and to make fertilizer and other chemicals. Coal is very polluting, both from a carbon dioxide perspective, and from the point of view of pollutants mixed with the coal. For many buyers, however, “cheap” trumps “good for the environment”.

A look at detail underlying China’s coal consumption makes it look as though the recent big increase in coal consumption began immediately after [China was admitted to the World Trade Organization](#), in December 2001. With more trade with the rest of the world, China had more need for coal to manufacture goods for export, and to build up its own internal infrastructure. The ultimate consumers, in the US and Europe, didn’t realize that it was their demand for cheap products from abroad that was fueling the rise in world coal consumption.

Addition of Oil to World Energy Mix

Oil was added to the energy mix in very small amounts, starting in the 1860s and 1870s. The amount added gradually increased through the years, with the really big increases coming after World War II. Oil filled several niches:

1. It was the first really *good* transportation fuel. It could be poured, so it was easy to put into a gas tank. It enabled door-to-door transportation, with automobiles, trucks, tractors for the farm, aircraft, and much construction equipment.
2. It (and the natural gas often associated with it) provided chemical fertilizer which could be used to cover up the huge soil deficiencies that had developed over the years. Hydrocarbons from oil also provide herbicides and insecticides. Oil also enabled the door-to-door transport of mineral additions to the soil mix, enhancing fertility.
3. Oil is very easy to transport in a can or truck, so it works well with devices like portable electric generators and irrigation pumps. It can be used where other fuels are hard to transport, such as small islands, with minimal equipment to make it usable.
4. With the huge change in transport enabled by oil, much greater international trade became possible. It became possible to regularly make complex goods, such as computers, with imports from many nations. It also became possible to import necessities, rather than using trade primarily for a few high-value goods.
5. Hydrocarbons could be made into medicines, enabling defeat of many of the germs that had in the past caused epidemics.
6. Hydrocarbons could be used to make plastics and fabrics, so that wood and crops grown to make fabrics (such as cotton and flax) would not be in such huge demand, allowing land to be used for other purposes.
7. Hydrocarbons could provide asphalt for roads, lubrication for machines, and many other hard-to-replace specialty products.
8. The labor-saving nature of machines powered by oil freed up time for workers to work elsewhere (or viewed less positively, sometimes left them unemployed).
9. The fact that tractors and other farm equipment took over the role of horses and mules after 1920 meant that more land was available for human food, since feed no longer needed to be grown for horses.

If we look at oil by itself (Figure 5, below), we see much more of a curved figure than for coal (Figure 4, above).

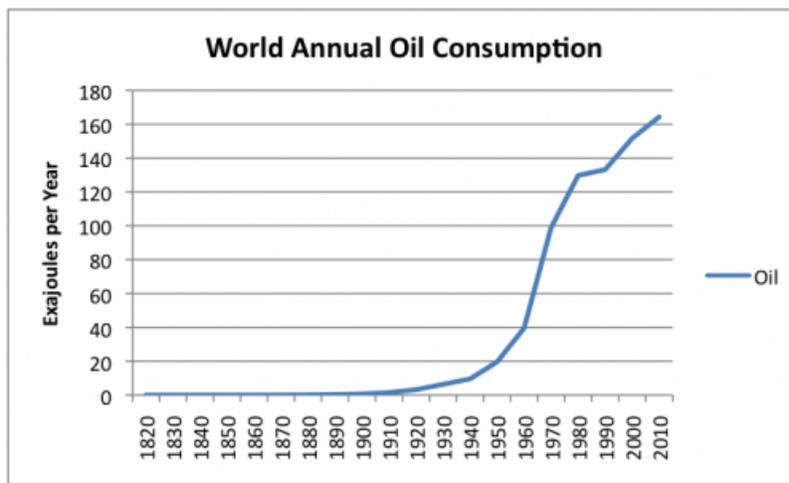


Figure 5. World annual oil consumption, based on the same data as in Figure 3 above. (Vaclav Smil /BP Statistical Review of World Energy)

My interpretation of this is that oil supply is more constrained than coal supply. Coal is cheap, and demand keeps growing. Oil has been rising in price in recent years, and the higher prices mean that consumers cut back on their purchases, to keep their budgets close to balanced. They can't afford as many vacations and can't afford to pave as many roads with asphalt. Oil is still the largest source of energy in the world, but coal is working on surpassing it. In a year or two, coal will likely be the world's largest source of energy. Together, they comprise about 60 percent of today's energy use.

If we look at per capita fuel consumption based on the same data as in Figure 3, this is what we see:

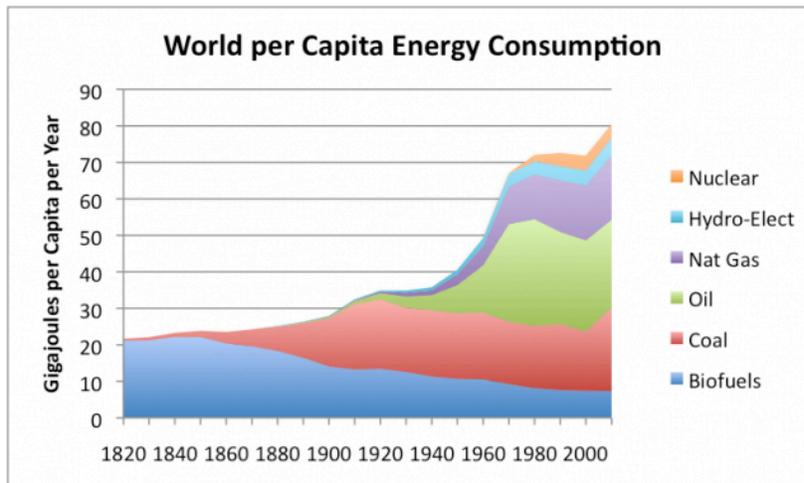


Figure 6. Per capita world energy consumption, calculated by dividing world energy consumption (based on Vaclav Smil estimates from [Energy Transitions: History, Requirements and Prospects](#) together with BP Statistical Data for 1965 and subsequent) by population estimates, based on [Angus Maddison data](#).

Figure 6 indicates that there was a real increase in total per capita energy consumption after World War II, about the time that oil consumption was being added in significant quantity. What happened was that coal consumption did not decrease (except to some extent on a per capita basis); oil was added on top of it.

If we look at world population growth for the same time period, we see a very distinct bend in the line immediately after World War II, as population rose as the same time as oil consumption.

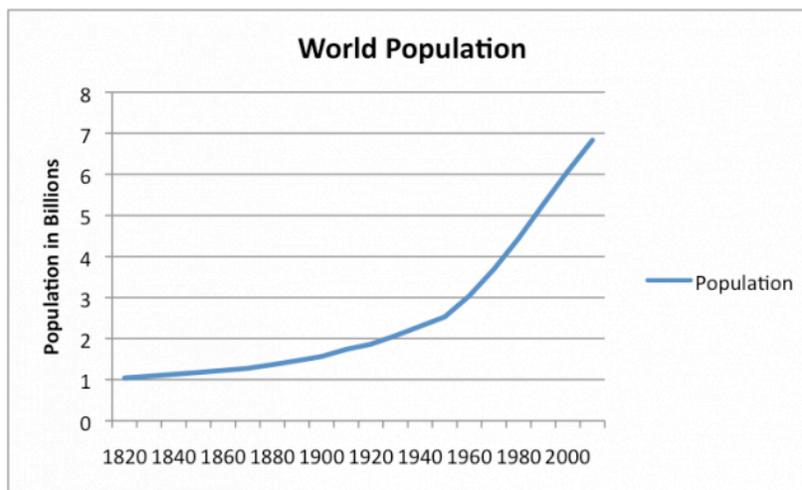


Figure 7. World Population, based on [Angus Maddison estimates](#), interpolated where necessary.

Clearly, the arrival of oil had a huge impact on agriculture. Unfortunately, the chemical fix for our long-standing soil problems is not a permanent ones. Soils need to be viewed as part of an ecological system, with biological organisms aiding in fertility. Soils also need an adequate amount of humus, if they are to hold water well in droughts. There are natural things that can be done to maintain soil fertility (add manure, terrace land, use perennial crops rather than annual crops, don't till the land). Unfortunately, using big machines dependent on oil, plus lots of chemical sprays, tends to operate in the opposite direction of building up the natural soil systems.

Our Energy Niche Problem

There are other fuels as well, including nuclear, wind energy, solar PV, solar thermal, biofuels, and natural gas. The production of all of these are enabled by the production of oil and coal, because of the large amount of metals involved in their production, and because of the need transport the new devices to a final location.

All of these other fuels tend have their own niches; it is hard for them to fill the big coal-oil niche on the current landscape. Solar thermal and natural gas are both directly heat-producing, and play a role that way. But it is hard to see how adequate metals production would continue with these fuels alone. Of course, with enough electricity, we could create the heat needed for metal production. The catch would be creating enough electricity.

“Cheap” is a very important characteristic of fuels to buyers. Coal is clearly beating out oil now in the area of “cheap”. Natural gas is the only one of the other energy sources that is close to cheap, at least in the United States. The catch with US natural gas is that producers can't really produce it cheaply, so its long-run prospects as a cheap fuel aren't good. Perhaps if the pricing issues can be worked out, US natural gas production can increase somewhat, but it is not likely to be the cheapest fuel.

One of the issues related to finding a replacement for oil and coal is that we already have a great deal of equipment (cars, trains, airplanes, farm equipment, construction equipment) that use oil, and we have many chemical processes that use oil or coal as an input. It would be very costly to make a change to another fuel, before the end of the normal lives of the equipment.

Wrapping Up

Over the long haul, energy sources have played a very large and varied role in the economy. In general, increases in the energy supply seem to correspond to increases in GDP and population. Necessary characteristics of energy supply are not always obvious. We don't think of low-cost as an important characteristic of energy products, but in the real world, this becomes an important issue.

As we move forward, we face challenges of many types. The world's population is still growing, and needs to be housed, clothed, and fed. None of the energy sources that is available is perfect. Our long history of using the land to produce annual crops has left the world with much degraded soil. The way forward is not entirely clear.

I will look at some related issues in upcoming posts.

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About Gail Tverberg

My name is Gail Tverberg. I am an actuary interested in finite world issues - oil depletion, natural gas depletion, water shortages, and climate change. The financial system is also likely to be affected.

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