MuseLetter

www.richardheinberg.com

richardheinberg.com

MuseLetter #226 / March 2011 by Richard Heinberg

This article is an excerpt from Chapter 4 of Richard's new book 'The End of Growth', which is set for publication by New Society Publishers in September 2011. Access previous chapters here.

Won't Innovation, Substitution, and Efficiency Keep Us Growing?

> I want to believe in innovation and its possibilities, but I am more thoroughly convinced of entropy. Most of what we do merely creates local upticks in organization in an overall downward sloping curve. In that regard, technology is a bag of tricks that allows us to slow and even reverse the trend, sometimes globally, sometimes only locally, but always only temporarily and at increasing aggregate energy cost.
> —*Paul Kedrosky (entrepreneur, editor of the econoblog Infectious Greed*)

In the course of researching and writing this book, I discussed its central thesis—that world economic growth has come to an end—with several economists, various businesspeople, a former hedge fund manager, a top-flight business consultant, and the former managing director of one of Wall Street's largest investment banks, as well as several ecologists and environmental activists. The most common reaction (heard as often from the environmentalists as the bankers) was along the lines of: "But capitalism has a few more tricks up its sleeve. It's infinitely creative. Even if we've hit environmental limits to energy or water, the mega-rich will find ways to amass yet more capital on the way down the depletion slope. It'll still look like growth to them."

Most economists would probably agree with the view that environmental constraints and a crisis in the financial world don't add up to the *end* of growth—just a speed bump in the highway of progress. That's because smart people will always be thinking of new technologies and of new ways to do more with less. And these will in turn be the basis of new commercial products and business models.

Talk of limits typically elicits dismissive references to the failed warnings of Thomas Malthus—the 18th century economist who reasoned that population growth would inevitably (and soon) outpace food production, leading to a general famine. Malthus was obviously wrong, at least in the short run: food production expanded throughout the 19th and 20th centuries to feed a fast-growing population. He failed to foresee the introduction of new hybrid crop varieties, chemical fertilizers, and the development of industrial farm machinery. The implication, whenever Malthus's ghost is summoned, is that *all* claims that environmental limits will overtake growth are likewise wrong, and for similar reasons. New inventions and greater efficiency will always trump looming limits.

In this chapter, we will examine the factors of efficiency, substitution, and innovation critically and see why—while these are key to our efforts to adapt to resource limits—they are incapable of removing those limits, and are themselves subject to the law of diminishing returns. And returns on investments in these strategies are in many instances already quickly diminishing.

Substitutes Forever

It is often said that "the Stone Age didn't end for lack of stones, and the oil age won't end for lack of oil; rather, it will end when we find a cheaper, better source of energy." Variations on that maxim have appeared in ads from ExxonMobil, statements from the Saudi Arabian government, and blogs from pro-growth think tanks—all arguing that the world faces no energy shortages, only energy opportunities.

It's true: the Stone Age ended when our ancient ancestors invented metal tools and found them to be superior to stone tools for certain purposes, not because rocks became scarce. Similarly, in the late-19th century early industrial economies shifted from using whale oil for lubrication and lamp fuel to petroleum, or "rock oil." Whale oil was getting expensive because whales were being hunted to the point that their numbers were dropping precipitously. Petroleum proved not only cheaper and more abundant, it also turned out to have a greater variety of uses. It was a superior substitute for whale oil in almost every respect.

Fast forward to the early 21st century. Now the cheap rock oil is gone. It's time for the next substitute to appear—a magic elixir that will make nasty old petroleum look as obsolete and impractical as whale oil. But what exactly is this "new oil"?

Economic theory is adamant on the point: as a resource becomes scarce, its price will rise until some other resource that can serve the same need becomes cheaper by comparison. That the replacement will prove superior is not required by theory.

Well, there certainly are substitutes for oil, but it's difficult to see any of them as superior—or even equivalent—from a practical, economic point of view.[1]

Just a few years ago, ethanol made from corn was hailed as the answer to our dependence on depleting, climate-changing petroleum. Massive amounts of private and public investment capital were steered toward the ethanol industry. Government mandates to blend ethanol into gasoline further supported the industry's development. But that experiment hasn't turned out well. The corn ethanol industry went through a classic boom-and-bust cycle, and expanding production of the fuel hit barriers that were foreseeable from the very beginning. It takes an enormous land area to produce substantial amounts of ethanol, and this reduces the amount of cropland available for growing food; it increases soil erosion and fertilizer pollution while forcing food prices higher. By 2008, soil scientists and food system analysts were united in opposing further ethanol expansion.[2]

But from an economic point of view the biggest problem with corn ethanol was its low energy return. The amount of energy required to grow the crop, harvest and collect it, and distill it into nearly pure alcohol was perilously close to the amount of energy that the fuel itself would yield when burned in an engine. This meant that ethanol wasn't really much of an energy source at all; making it was just a way of taking existing fuels (petroleum and natural gas) and using them (in the forms of tractor fuel, fertilizer, and fuel for distillation plants) to produce a different fuel that could be used for the same purposes as gasoline. Experts argued back and forth: one critic said the energy balance of corn ethanol was actually negative (less than 1:1)—meaning that ethanol was a losing proposition on a net energy basis.[3] But then a USDA study claimed a positive energy balance of 1.34:1.[4] Other studies yielded slightly varying numbers (the differences had to do with deciding which energy inputs should be included in the analysis).[5]

From a broader perspective, this bickering over decimal-place accuracy was pointless: in its heyday, oil had enjoyed an EROEI *[energy returned on energy invested]* of 100:1 or more, and it is clear that for an industrial society to function it needs primary energy sources with a minimum EROEI of between 5:1 and 10:1.[6] With an overall societal EROEI of 3:1, for example, roughly a third of all of that society's effort would have to be devoted just to obtaining the energy with which to accomplish all the other things that a society must do (such as manufacture products, carry on trade, transport people and goods, provide education, engage in scientific research, and maintain basic infrastructure). Since even the most optimistic EROEI figure for corn ethanol is significantly below that figure, it is clear that this fuel cannot serve as a primary energy source for an industrial society like the United States.

The problem remains for so-called second- and third-generation biofuels—cellulosic ethanol made from forest and crop wastes and biodiesel squeezed from algae. Extraordinary preliminary claims are being made for the potential scalability and energy balance of these fuels, which so far are still in the experimental stages, but there is a basic reason for skepticism about such claims. With all biofuels we are trying to do something inherently very difficult—replace one fuel, which nature collected and concentrated, with another fuel whose manufacture requires substantial effort on our part to achieve the same result. Oil was produced over the course of tens of millions of years without need for any human work. Ancient sunlight energy was chemically gathered and stored by vast numbers of microscopic aquatic plants, which fell to the bottoms of seas and were buried under sediment and slowly transformed into energy-dense hydrocarbons. All we have had to do was drill down to the oil-bearing rock strata, where the oil itself was often under great pressure so that it flowed easily up to the surface. To make biofuels, we must engage in a variety of activities that require large energy expenditures for growing and fertilizing crops, gathering crops or crop residues, pressing algae to release oils, maintaining and cleaning algae bioreactors, or distilling alcohol to a high level of purity (this is only a partial list). Even with substantial technical advances in each of these areas, it will be impossible to compete with the high level of energy payback that oil enjoyed in its heyday.

This is not to say that biofuels have no future. As petroleum becomes more scarce and expensive we may find it essential to have modest quantities of alternative fuels available for certain purposes even if those alternatives are themselves expensive, in both monetary and energy terms. We will need operational emergency vehicles, agricultural machinery, and some aircraft, even if we have to subsidize them with energy we might ordinarily use for other purposes. In this case, biofuels will not serve as one of our society's primary energy sources—the status that petroleum enjoys today. Indeed, they will not comprise much of an energy *source* at all in the true sense, but will merely serve as a means to transform energy that is already available into fuels that can be used in existing engines in order to accomplish selected essential goals. In other words, biofuels will substitute for oil on an emergency basis, but not in a systemic way.

The view that biofuels are unlikely to fully substitute for oil anytime soon is supported by a recent University of California (Davis) study that concludes, on the basis of market trends only, that "At the current pace of research and development, global oil will run out 90 years before replacement technologies are ready."[7]

It could be objected that we are thinking of substitutes too narrowly. Why insist on maintaining current engine technology and simply switching the fuel? Why not use a different drive train altogether?

Electric cars have been around nearly as long as the automobile itself. Electricity could clearly serve as a substitute for petroleum—at least when it comes to ground transportation (aviation is another story—more on that in a moment). But the fact that electric vehicles have failed for so long to compete with gasoline- and diesel-powered vehicles suggests there may be problems.

In fact, electric cars have advantages as well as disadvantages when compared to fuel-burning cars. The main advantages of electrics are that their energy is used more efficiently (electric motors translate nearly all their energy into motive force, while internal combustion engines are much less efficient), they need less drive-train maintenance, and they are more environmentally benign (even if they're running on coal-derived electricity, they usually entail lower carbon emissions due to their much higher energy efficiency). The drawbacks of electric vehicles have to do with the limited ability of batteries to store energy, as compared to conventional liquid fuels. A gallon of gasoline carries 42 megajoules of energy per kilogram, while lithium-ion batteries can store only 0.5 MJ/kg. Improvements are possible, but the theoretical limit of chemical energy storage is still only about 3 MJ/kg.[8] This is why we'll never see battery-powered airliners: the batteries would be way too heavy to allow planes to get off the ground. This doesn't mean research into electric aircraft should not be pursued: There have been successful experiments with ultra-light solar-powered planes, and electric planes could come in handy in a future where most transport will be by boat, rail, bicycle, or foot. But these will be special-purpose aircraft that can carry only one or two passengers.

The low energy density (by weight) of batteries tends to limit the range of electric cars. This problem can be solved with hybrid power trains—using a gasoline engine to charge the batteries, as in the Chevy Volt, or to push the car directly part of the time, as with the Toyota Prius—but that adds complexity and expense.

So substituting batteries and electricity for petroleum works in some instances, but even in those cases it offers less utility (if it offered *more* utility, we would all already be driving electric cars).[9]

Increasingly, substitution is less economically efficient. But surely, in a pinch, can't we just accept the less-efficient substitute? In emergency or niche applications, yes. But if the less-efficient substitute must replace a resource of profound economic importance (like oil), or if a large number of resources have to be replaced with less-useful substitutes, then the overall result for society is a reduction—perhaps a sharp reduction—in its capacity to achieve economic growth.

As we saw in Chapter 3, in our discussion of the global supply of minerals, when the quality of an ore drops the amount of energy required to extract the resource rises. All over the world mining companies are reporting declining ore quality.[10] So in many if not most cases it is no longer possible to substitute a rare, depleting resource with a more abundant, cheaper resource; instead, the available substitutes are themselves already rare and depleting.

Theoretically, the substitution process can go on forever—as long as we have endless energy with which to obtain the minerals we need from ores of ever-declining quality. But to produce that energy we need more resources. Even if we are using only renewable energy, we need steel for wind turbines and coatings for photovoltaic panels. And to extract *those* resources we need still more energy, which requires more resources, which requires more energy. At every step down the ladder of resource quality, more energy is needed just to keep the resource extraction process going, and less energy is available to serve human needs (which presumably is the point of the exercise).[11]

The issues arising with materials synthesis are very similar. In principle it is possible to synthesize oil from almost any organic material. We can make petroleum-like fuels from coal, natural gas, old tires, even garbage. However, doing so can be very costly, and the process can consume more energy than the resulting synthetic oil will deliver as a fuel, unless the material we start with is already very similar to oil.

It's not that substitution can never work. Recent years have seen the development of new catalysts in fuel cells to replace depleting, expensive platinum, and new ink-based materials for photovoltaic solar panels that use copper indium gallium diselenide (CIGS) and cadmium telluride to replace single-crystalline silicon. And of course renewable wind, solar, geothermal, and tidal energy sources are being developed and deployed as substitutes for coal.

We will be doing a lot of substituting as the resources we currently rely on deplete. In fact, materials substitution is becoming a primary focus of research and development in many industries. But in the most important cases (including oil), the substitutes will probably be inferior in terms of economic performance, and therefore will not support economic growth.

References

1. For an excellent discussion of whether the shift from cheap conventional oil to expensive non-conventional liquid fuels constitutes "substitution" in the economic sense, see David Murphy, "Does Peak Oil Even Matter?," *The Oil Drum*, December 17, 2010,http://www.theoildrum.com/node/7246#more.
2. Environmental Protection Agency,*Biofuels and the Environment: The First Triennial Report to Congress, Draft Report EPA/600/R-10/183A, January 28, 2011.*
3. David Pimentel and Tad W. Patzek, "Ethanol Production Using Corn, Switchgrass and Wood; Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research* 14, no.1 (March 2005).
4. Hosein Shapouri, James Duffield, and Michael Wang, "The Energy Balance of Corn Ethanol: An Update," *U.S. Department of Agriculture*, Office of Energy Policy and New Uses, Report No. 813, 2002.
5. David Pimental and Tad Patzek, "Ethanol Production Using Corn, Switchgrass and Wood: Biodiesel Production Using Soybean and Sunflower," *Natural Resources Research* 14, no.1 (March 2005); Adam Liska et al., "Improvements in Life Cycle Energy Efficiency and Greenhouse Gas Emissions of Corn Ethanol," *J. Industrial Ecology*, 13, no.1 (2009); Jason Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences*103 (July 25, 2006).
6. Charles A.S. Hall and the 'EROI Study Team,' "Provisional Results from EROI Assessments," *The Oil Drum*, posted April 8, 2008, http://www.theoildrum.com/node/3810.
7. "New Forecast Warns Oil Will Run Dry Before Substitutes Roll Out," *UC Davis News Service*, posted November 9, 2010; Helen Knight, "Green Machine: Markets Hint at 100-Year Energy Gap," *New Scientist online*, posted November 11, 2010.
8. Kurt Zenz House, "The Limits of Energy Storage Technology," *Bulletin of the Atomic Scientists*, January 20, 2009.
9. Aeldric, "The Networking of Resource Production: Do the Networks Give Us Warnings When They Are About to Fail?" *The Oil Drum*, posted September 22, 2010, http://anz.theoildrum.com/node/6974#more.
10. See, for example, "Iron Ores," *Highbeam Business*, 2011, http://business.highbeam.com/industry-reports/mining/iron-ores; and Chanyaporn Chanjaroen, "Escondida Copper Production Will Decline Up to 10% on Ore Grades, BHP Says," *Bloomberg*, posted August 25, 2010.
11. Ugo Bardi, "The Universal Mining Machine," *The Oil Drum*, posted January 24, 2008, http://europe.theoildrum.com/node/3451.