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This article is an excerpt from Chapter 3 of Richard's new book 'The End of Growth', which is set for publication by New Society Publishers in July 2011. Given the urgency and fragility of the global economic crisis, we are serializing the draft content as Richard writes it. Access previous chapters here.

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Earth's Limits:
Why Growth Won't Return

> *The 2008 crude oil price, $147 per barrel, shattered the global economy. The "invisible hand" of economics became the invisible fist, pounding down world economic growth to match the limitations of crude oil production.*
> *—Kenneth Deffeyes (petroleum geologist)*

We have just seen why, since 2007, growth has languished for reasons internal to the world financial system—the system of money and debt.

Problems arising from speculative overreach, real estate bubbles, and the inherent Ponzi dynamics of our global debt-based financial structures are endemic and profound. Still, if these were our only difficulties, we might reasonably expect that eventually, once they are sorted out (however painful the process may be), growth will return.

Indeed, that is what nearly everyone assumes. It's a matter of "when," not "if" growth resumes.

But there are seldom-acknowledged factors *external* to financial and monetary systems that are effectively choking off efforts to restart growth. These factors, whose impacts are worsening over time, were briefly alluded to in the Introduction; here we will unpack them in more detail, discussing limits to oil and other energy sources, as well as to food, water, and minerals. We will also explore the increasing cost of industrial accidents and environmental disasters—and why, in the wide wake of global climate change, those costs are likely to escalate to the point that disaster avoidance and recovery will constitute a major portion of future government and private spending. Along the way, we will examine how markets respond to resource scarcity (it's not a clear-cut matter of incrementally rising prices).

Crucially, in this chapter we will see how and why the most important of these non-financial limits to economic expansion are matters of concern not just for future generations, but for markets and policy makers—indeed, for everyone—*today*.

Oil

In the Introduction we briefly surveyed the Peak Oil scenario and the events surrounding the oil price spike of 2008. It is tempting here to launch into a lengthy discussion of Peak Oil and what it means to industrial society. I've been writing about this subject for over a decade, and it would be easy to fill the space between these covers simply with updates to existing publications. But that's not what is required here; for our immediate purposes, all that is needed is an overview of some main points regarding oil depletion that are relevant to the question of whether and how economies can continue growing. Readers who wish to know more about Peak Oil should refer to sources listed in the end notes.[1]

When discussion turns to the economy, most of the ensuing talk tends to focus on money—prices, wages, and interest rates. Yet as important as money is to economies, energy is even more basic. Without energy, nothing happens—quite literally. Energy is not just a commodity; it is the prerequisite for any and all activity. No energy, no economy. (In the next chapter we will examine the argument that we can produce economic growth while using *less* energy—by using energy more efficiently; our conclusion will be that this is possible only to a limited extent and in situations that differ fundamentally from our current one.)

The massive worldwide economic growth of the past two centuries was enabled by humanity's newfound ability to exploit the cheap, abundant energy of fossil fuels. There were of course other factors at work—including division of labor, technological innovation, and increased trade. But if it weren't for oil, coal, and natural gas, we would today all probably be living an essentially agrarian existence similar to that of our 18^{th} century ancestors—though perhaps with a few additional though minor wind- and water-powered industrial accoutrements.

Growth requires not just energy in the most general sense, but forms of energy with specific characteristics. After all, the Earth is constantly bathed in energy—indeed, the amount of solar energy that falls on Earth's surface each *minute* is greater than the amount of fossil-fuel energy the world uses every *year.* But sunlight energy is diffuse and difficult to use directly. Economies need sources of energy that are concentrated and controllable, and that can be made to do useful work. From a short-term point of view, fossil fuels proved to be energy sources with highly desirable characteristics: they could be extracted from Earth's crust quite cheaply (at least in the early days), they were portable, and they delivered a lot of energy per unit of weight and/or volume—in most instances, far more than the firewood that people had been accustomed to using.

Oil has the particular advantage of being a liquid, which means that it (and its refined products like gasoline and jet fuel) can easily be stored in tanks and pumped through pipes and hoses. This effectively maximizes portability. As a result, oil has become the basis of world transport systems, and therefore of world trade. If the oil stops flowing, global trade as we know it grinds to a standstill.

The phrase "Peak Oil" is often misunderstood to refer to the total exhaustion of petroleum resources—*running out.* In fact it just signifies the period when the production of oil achieves its maximum rate before beginning its inevitable decline. This peaking and decline of production has already been observed in thousands of individual oilfields and in the total national oil production of many countries including the U.S., Indonesia, Norway, Great Britain, Oman, and Mexico. Global Peak Oil will certainly occur, of that there can be no doubt. There is still some controversy about the timing of the event: has it already happened, will it occur soon, or can it be delayed for many years or even decades?

In 2010, the International Energy Agency settled the matter. In its authoritative 2010 *World Energy Outlook*, the IEA announced that total annual global crude oil production will probably never surpass its 2006 level.[2] However, the agency fudged the question a bit by declaring that the peak was not due to geological constraints, and that total volumes of liquid fuels (including crude oil, biofuels, synthetic oil from tar sands and coal, and natural gas liquids like butane and propane) will continue to grow—just a bit—until 2035. In discussing the IEA report, a few analysts declared that these latter claims were essentially just efforts to avoid panicking the markets.[3]

Scientists who study oil depletion begin with the premise that, for any non-renewable resource such as petroleum, exploration and production proceed on the basis of the best-first or low-hanging fruit principle. Because petroleum geologists began their hunt for oil by searching easily accessible onshore regions of the planet, and because large targets are easier to hit than small ones, the biggest and most conveniently located oilfields tended to be found early in the discovery process.

The largest oilfields—nearly all of which were identified in the decades of the 1930s through the 1960s—were behemoths, each containing billions of barrels of crude and producing oil during their peak years at rates of from hundreds of thousands to several millions of barrels per day. But only a few of these "super-giants" were found. Most of the world's other oilfields, numbering in the thousands, are far smaller, containing a few thousand up to a few million of barrels of oil and producing it at a rate of anywhere from a few barrels to several thousand barrels per day. As the era of the super-giants passes, it becomes ever more difficult and expensive to make up for their declining production of cheap petroleum with oil from newly discovered oilfields that are smaller and less accessible, and therefore on average more costly to find and develop. As Jeremy Gilbert, former chief petroleum engineer for BP, has put it, "The current fields we are chasing we've known about for a long time in many cases, but they were too complex, too fractured, too difficult to chase. Now our technology and understanding [are] better, which is a good thing, because these difficult fields are all that we have left."[4]

The trends in the oil industry are clear and undisputed: exploration and production are becoming more costly, and are entailing more environmental risks, while competition for access to new prospective regions is generating increasing geopolitical tension. The rate of oil discoveries on a worldwide basis has been declining since the early 1960s, and most exploration and discovery are now occurring in inhospitable regions such as in ultra-deepwater (at ocean depths of up to three miles) and the Arctic, where operating expenses and environmental risks are extremely high.[5] This is precisely the situation we should expect to see as the low-hanging fruit disappear and global oil production nears its all-time peak in terms of flow rate.

While the U.S. Department of Energy and the IEA continue to produce mildly optimistic forecasts suggesting that global liquid fuels production will continue to grow until at least 2030 or so, these forecasts now come with a semi-hidden caveat: *as long as implausibly immense investments in exploration and production somehow materialize*. This hedged sanguinity is echoed in statements from ExxonMobil and Cambridge Energy Research Associates, as well as a few energy economists. Nevertheless, it is fair to say that most serious analysts now expect a near-term (i.e., within the current decade) commencement of decline in global crude oil *and* liquid fuels production. A survey last year of about a hundred of the world's most respected petroleum geologists by the Association for the Study of Peak Oil (ASPO) found that the vast majority expected world oil production to peak between 2010 and 2020.[6] Prominent oil industry figures such as Charles Maxwell and Boone Pickens say the peak either already has happened or will do so soon.[7] And recent detailed studies by governments and industry groups reached this same conclusion.[*8*] Toyota, Virgin Airlines, and other major fuel price-sensitive corporations routinely include Peak Oil in their business forecasting models.[9]

Examined closely, the arguments of the Peak Oil naysayers actually boil down to a tortuous effort to say essentially the same things as the Peaksters do, but in less dramatic (some would say *less accurate and useful*) ways: Cornucopian pundits like Daniel Yergin of Cambridge Energy Research Associates speak of a peak not in *supply*, but in *demand* for petroleum (but of course, this reduction in demand is being driven by rising oil prices—so what exactly is the difference?).[10] Or they emphasize that the world is seeing the end of *cheap* oil, not of oil *per se*. They point to enormous and, in some cases, growing petroleum reserves worldwide—yet close examination of these alleged reserves reveals that most consist of "paper reserves" (claimed numbers based on no explicit evidence), or bitumen and other oil-related substances that require special extraction and processing methods that are slow, expensive, and energy-intensive. Read carefully, the statements of even the most ebullient oil boosters confirm that the world has entered a new era in which we should expect prices of liquid fuels to remain at several times the inflation-adjusted levels of only a few years ago.

Quibbling over the exact meaning of the word "peak" or the exact timing of the event, or what constitutes "oil" is fairly pointless. The oil world has changed. And this powerful shock to the global energy system has just happened to coincide with a seismic shift in the world's economic and financial systems.

The likely consequences of Peak Oil have been explored in numerous books, studies, and reports, and include severe impacts on transport networks, food systems, global trade, and all industries that depend on liquid fuels, chemicals, plastics, and pharmaceuticals.[11] In sum, most of the basic elements of our current way of life will have to adapt or become unsupportable. There is also a strong likelihood of increasing global conflict over remaining oil resources.[12]

Of course, oil production will not cease instantly at the peak, but will decline slowly over several decades; therefore these impacts will appear incrementally and cumulatively, punctuated by intermittent economic and geopolitical crises driven by oil scarcity and price spikes.

Oil importing nations (including the U.S. and most of Europe) will see by far the worst consequences. That's because oil that is available for the export market will dwindle much more quickly than total world oil production, since oil producers will fill domestic demand before servicing foreign buyers, and many oil exporting nations have high rates of domestic demand growth.[13]

Other Energy Sources

Oil is not our only important energy source, nor will its depletion present the only significant challenge to future energy supplies. Coal and natural gas are also pivotal contributors to global energy; they are also fossil fuels, are also finite, and are therefore also subject to the low-hanging fruit principle of extraction. We use these fuels mostly for making electricity, which is just as essential to modern civilization as globe-spanning transport networks. When the electricity goes out, cities go dark, computers blink off, and cash registers fall idle.

As with oil, we are not about to *run out* of either coal or gas. However, here again costs of production are rising, and limits to supply growth are becoming increasingly apparent.[14]

The peak of world coal production may be only years away, as discussed in my 2009 book *Blackout: Coal, Climate and the Last Energy Crisis.* Indeed, one peer-reviewed study published in 2010 concluded that the amount of energy derived from coal globally could peak as early as this year.[15] Some countries that latched onto the coal bandwagon early in the industrial period (such as Britain and Germany) have been watching their production decline for decades. Industrial latecomers are catching up fast by depleting their reserves at phenomenal rates. China, which relies on coal for 70 percent of its energy and has based its feverish economic growth on rapidly growing coal consumption, is now using over 3 billion tons per year—triple the usage rate of the U.S. Declining domestic Chinese coal production (the national peak will almost certainly occur within the next five to ten years) will lead to more imports, and will therefore put pressure on global supplies.[16] We will explore the implications for China's economy in more detail in Chapter 5.

In the U.S., most experts still rely on decades-old coal reserves assessments that are commonly (though erroneously) interpreted as indicating that the nation has a 250-year supply. This reliance on outdated and poorly digested data has lulled energy planners, policy makers, and the general public into a dangerous complacency. In terms of the energy it yields, domestic coal production peaked in the late 1990s (more coal is being mined today in raw tonnage, but the coal is of lower and steadily declining energy content). Recent U.S. Geological Survey assessments of some of the most important mining regions show rapid depletion of accessible reserves.[17] No one doubts that there is still an enormous amount of coal in the U.S., but the idea that the nation can increase total energy production from coal in the years ahead is highly doubtful.

Add to this an exploding Chinese demand for coal imports, and the inevitable result will be steeply rising coal prices globally, even in nations that are currently self-sufficient in the resource. Higher coal prices will in turn torpedo efforts to develop "clean coal" technologies, which on their own are projected to add significantly to the cost of coal-based electricity.[18]

OECD energy demand declined in response to the 2008 financial crisis. If financial turmoil (with resulting reductions in employment and consumption) were to continue in the U.S. and Europe and spread to China, this could help stretch out world coal supplies and keep prices relatively lower. But an economic recovery would quickly lead to much higher energy prices—which in turn would likely force many economies back into recession.

The future of world natural gas supplies is a bit murkier. Conventional natural gas production is declining in many nations, including the U.S.[19]However, in North America new unconventional production methods based on hydro-fracturing of gas-bearing rocks of low permeability are making significantly larger quantities of gas available, at least over the short term—though at a higher production cost. Due to the temporary supply glut, this higher cost has yet to be reflected in gas prices (currently most of the companies that specialize in gas "fracking" are subsisting on investment capital rather than profits from production, because natural gas prices are not high enough to make production profitable, in most instances).[20] Higher-than-forecast depletion rates add to doubts about whether unconventional gas will be a global game-changer, as it is being called by its boosters, or merely an expensive, short-term, marginal addition to supplies of what will soon be a declining source of energy.[21]

Can other energy sources replace fossil fuels? Some alternatives, such as wind, are seeing rapid growth rates, but still account for only a minuscule share of current global energy supplies. Even if they maintain high rates of growth, they are unlikely to become primary energy sources in any but a small handful of nations by 2050.

In 2009 Post Carbon Institute and the International Forum on Globalization undertook a joint study to analyze 18 energy sources (from oil to tidal power) using 10 criteria (scalability, renewability, energy density, energy returned on energy invested, and so on). While I was the lead author of the ensuing report (*Searching for a Miracle: Net Energy Limits and the Fate of Industrial Societies*), my job was essentially just to synthesize original research and analysis from many energy experts.[22] It was, to my knowledge, the first time so many energy sources had been examined using so many essential criteria. Our conclusion was that there is no credible scenario in which alternative energy sources can entirely make up for fossil fuels as the latter deplete. The overwhelming likelihood is that, by 2100, global society will have *less* energy available for economic purposes, not more.[23]

Here are some relevant passages from that report:

> *A full replacement of energy currently derived from fossil fuels with energy from alternative sources is probably impossible over the short term; it may be unrealistic to expect it even over longer time frames. . . . [U]nless energy prices drop in an unprecedented and unforeseeable manner, the world's economy is likely to become increasingly energy-constrained as*

> *fossil fuels deplete and are phased out for environmental reasons. It is highly unlikely that the entire world will ever reach an American or even a European level of energy consumption, and even the maintenance of current energy consumption levels will require massive investment. . . . Fossil fuel supplies will almost surely decline faster than alternatives can be developed to replace them. New sources of energy will in many cases have lower net energy profiles than conventional fossil fuels have historically had, and they will require expensive new infrastructure to overcome problems of intermittency.[24]*

Some other studies have reached different, more sanguine conclusions. We believe that this is because they failed to take into account some of the key criteria on which we focused, including the amount of energy returned on the energy that's invested in producing energy (EROEI). Energy sources with a low EROEI cannot be counted as potential primary sources for industrial societies.[25]

As a result of this analysis, we believe that the world has reached immediate, non-negotiable energy limits to growth.[26]

How Markets May Respond to Resource Scarcity: The Goldilocks Syndrome

Before examining limits to non-energy resources, it might be helpful to consider how markets respond to resource scarcity, with petroleum as a highly relevant case in point.

The standard economic assumption is that, as a resource becomes scarce, prices will rise until some other resource that can fill the same need becomes cheaper by comparison. What really happens, when there is no ready substitute, can perhaps best be explained with the help of a little recent history and an old children's story.

Once upon a time (about a dozen years past), oil sold for $20 a barrel in inflation-adjusted figures, and *The Economist* magazine ran a cover story explaining why petroleum prices were set to go much lower.[27] The U.S. Department of Energy and the International Energy Agency were forecasting that, by 2010, oil would probably still be selling for $20 a barrel, but they also considered highly pessimistic scenarios in which the price could rise as high as $30 (those forecasts are in 1996 dollars).[28]

Instead, as the new decade wore on, the price of oil soared relentlessly, reaching levels far higher than the "pessimistic" $30 range. Demand for the resource was growing, especially in China and some oil exporting nations like Saudi Arabia; meanwhile, beginning in 2005, actual world oil production hit a plateau. Seeing a perfect opportunity (a necessary commodity with stagnating supply and growing demand), speculators drove the price up even further.

As prices lofted, oil companies and private investors started funding expensive projects to explore for oil in remote and barely accessible places, or to make synthetic liquid fuels out of lower-grade carbon materials like bitumen, coal, or kerogen.

But then in 2008, just as the price of a barrel of oil reached its all-time high of $147, the economies of the OECD countries crashed. Airlines and trucking companies downsized and motorists stayed home. Demand for oil plummeted. So did oil's price, bottoming out at $32 at the end of 2008.

But with prices this low, investments in hard-to-find oil and hard-to-make substitutes began to look tenuous, so tens of billions of dollars' worth of new energy projects were canceled or delayed. Yet the industry had been counting on those projects to maintain a steady stream of liquid fuels a few years out, so worries about a future supply crunch began to make headlines.[29]

It is the financial returns on their activities that motivate oil companies to make the major investments necessary to find and produce oil. There is a long time lag between investment and return, and so price stability is a necessary condition for further investment.

Here was a conundrum: low prices killed future supply, while high prices killed immediate demand. Only if oil's price stayed reliably within a narrow —and narrowing—"Goldilocks" band could serious problems be avoided. Prices had to stay not too high, not too low—just right—in order to avert economic mayhem.[30]

The gravity of the situation was patently clear: Given oil's pivotal role in the economy, high prices did more than reduce demand, they had helped undermine the economy as a whole in the 1970s and again in 2008. Economist James Hamilton of the University of California, San Diego, has assembled a collection of studies showing a tight correlation between oil price spikes and recessions during the past 50 years. Seeing this correlation, every attentive economist should have forecast a steep recession beginning in 2008, as the oil price soared. "Indeed," writes Hamilton, "the relation could account for the entire downturn of 2007-08. . . . If one could have known in advance what happened to oil prices during 2007-08, and if one had used the historically estimated relation [between oil price spikes and economic impacts] . . . one would have been able to predict the level of real GDP for both of 2008:Q3 and 2008:Q4 quite accurately." [31]

This is not to ignore the roles of too much debt and the exploding real estate bubble in the ongoing global economic meltdown: As we saw in the previous two chapters, the economy was set up to fail regardless of energy prices. But the impact of the collapse of the housing market could only have been amplified by an inability to increase the rate of supply of depleting petroleum. Hamilton again: "At a minimum it is clear that something other than [I would say: "in addition to"] housing deteriorated to turn slow growth into a recession. That something, in my mind, includes the collapse in automobile purchases, slowdown in overall consumption spending, and deteriorating consumer sentiment, in which the oil shock was indisputably a contributing factor."

Moreover, Hamilton notes that there was "an interaction effect between the oil shock and the problems in housing." That is, in many metropolitan areas, house prices in 2007 were still rising in the zip codes closest to urban centers but already falling fast in zip codes where commutes were long.[32]

By mid-2009 the oil price had settled within the "Goldilocks" range—not too high (so as to kill the economy and, with it, fuel demand), and not too low (so as to scare away investment in future energy projects and thus reduce supply). That just-right price band appeared to be between $60 and $80 a barrel.[33]

How long prices can stay in or near the Goldilocks range is anyone's guess (as of this writing, oil is trading in New York for over $90 per barrel), but as declines in production in the world's old super-giant oilfields continue to accelerate and exploration costs continue to mount, the lower boundary of that just-right range will inevitably continue to migrate upward. And while the world economy remains frail, its vulnerability to high energy prices is more pronounced, so that even $80-85 oil could gradually weaken it further, choking off signs of recovery.[34]

In other words, oil prices have effectively put a cap on economic recovery.[35] This problem would not exist if the petroleum industry could just get busy and make a lot more oil, so that each unit would be cheaper. But despite its habitual use of the terms "produce" and "production," the industry doesn't *make* oil, it merely *extracts* the stuff from finite stores in the Earth's crust. As we have already seen, the cheap, easy oil is gone. Economic growth is hitting the Peak Oil ceiling.

As we consider other important resources, keep in mind that the same economic phenomenon may play out in these instances as well, though perhaps not as soon or in as dramatic a fashion. Not many resources, when they become scarce, have the capability of choking off economic activity as directly as oil shortages can. But as more and more resources acquire the Goldilocks syndrome, general commodity prices will likely spike and crash repeatedly, making a hash of efforts to stabilize the economy.

References
1. Peak Oil sources. *The Party's Over,* www.TheOilDrum.com, ASPO USA
2. "…[In 2035] Global oil production reaches 96 mb/d, the balance of 3 mb/d coming from processing gains. Crude oil output reaches an undulating plateau of around 68-69 mb/d by 2020, but never regains its all-time peak of 70 mb/d reached in 2006, while production of natural gas liquids (NGLs) and unconventional oil grows strongly." International Energy Agency, "Executive Summary," *World Energy Outlook 2010* (Paris: OECD/IEA,2010),6; Also see the graph "World oil production by type in the New Policies Scenario," IEA, "Key Graphs," *World Energy Outlook 2010*, http://www.worldenergyoutlook.org/docs/weo2010/key_graphs.pdf.
3. Kjell Aleklett, "Spin Slips Off Production Numbers – World Energy Outlook 2010 is a Cry For Help," *Aleklett's Energy Post*, posted November 11, 2010.
4. Jeremy Gilbert, "No We Can't: Uncertainty, Technology, and Risk," presented at the ASPO-USA 2010 Peak Oil Conference, Washington, D.C., October 9, 2010.
5. Jessica Bachman, "Special Report: Oil and Ice: Worse Than the Gulf Spill?" *Reuters.com*, posted November 8, 2010.
6. survey of geologists by ASPO
7. Charles Maxwell, quoted in Wallace Forbes, "Bracing For Peak Oil Production by Decade's End," *Forbes.com*, posted September 13, 2010; Eoin O'Carroll, "Pickens: Oil Production Has Peaked," *The Christian Science Monitor*, posted June 18, 2008.
8. Clint Smith, "New Zealand Parliament Peak Oil Report: The Next Oil Shock?" *Energy Bulletin*, posted October 1,

2010, http://www.energybulletin.net/stories/2010-10-14/next-oil-shock; Stefan Schultz, "Military Study Warns of a Potentially Drastic Oil Crisis," *Spiegel Online*, posted September 1, 2010; UK Industry study; U.S. Joint Forces Command, *The Joint Operating Environment 2010 (Suffolk, VA: USJFCOM, 2010).*
9. Toyota, Virgin Airlines, and other major fuel price-sensitive corporations routinely include Peak Oil in their business forecasting models.
10. Ben German, "The Other Peak Oil: Demand From Developed World Falling." *Scientific American*, October 13, 2009.
11. Robert L. Hirsch, Roger Bezdek, and Robert Wendling, Peaking of World Oil Production: Impacts, Mitigation, & Risk Management," a report for the U.S. Department of Energy, National Energy Technology Laboratory, February 2005; Stefan Schultz, "Military Study Warns of a Potentially Drastic Oil Crisis," *Spiegel Online*, posted September 1, 2010.
12. Michael Klare, *Blood and Oil: The Dangers and Consequences of America's Growing Petroleum Dependency* (New York: Henry Holt and Co., 2004) ; Michael Klare, *Rising Powers, Shrinking Planet: the New Geopolitics of Energy* (New York: Henry Holt and Co., 2008).
13. Jeffrey Brown and Sam Foucher, "Peak Oil Versus Peak Exports," *Energy Bulletin*, posted October 18, 2010, http://www.energybulletin.net/stories/2010-10-18/peak-oil-versus-peak-exports; Gail the Actuary, "Verifying the Export Land Model – A Different Approach," *The Oil Drum*, posted October 1, 2010, http://www.theoildrum.com/node/7007#more.
14. Buttonwood, "Engine Trouble: A Rise in the Cost of Extracting Energy Will Hit Productivity," *The Economist*, October 1, 2010.
15. Tadeusz W. Patzek and Gregory D. Croft, "A Global Coal Production Forecast with Multi-Hubbert Cycle Analysis," *Energy* 35 (2010), 3109-3122; S.H. Mohr and G.M. Evans, "Forecasting Coal Production Until 2100," *Fuel* 88 (2009), 2059-2067.
16. Richard Heinberg and David Fridley, "The End of Cheap Coal," *Nature* 468 (November 18, 2010), 367-369.
17. Recent U.S. Geological Survey assessments of some of the most important mining regions show rapid depletion of accessible reserves. U.S. Geological Survey, *Coal Reserves of the Matewan Quadrangle, Kentucky – A Coal Recoverability Study*, U.S. Bureau of Mines Circular 9355, http://pubs.usgs.gov/usbmic/ic-9355/C9355.htm; James Luppens et al., *Assessment of Coal Geology, Resources, and Reserves in the Gillette Coalfield, Powder River Basin, Wyoming*, USGS Open-File Report 2008-1202, 2008, http://pubs.usgs.gov/of/2008/1202/.
18. Zaipu Tao and Mingyu Li, "What Is the Limit of Chinese Coal Supplies – A STELLA Model of Hubbert Peak," *Energy Policy* 35, no.6 (June, 2007), 3145-3154; WorleyParsons et al., *Strategic Analysis of the Global Status of Carbon Capture and Storage* (Global CCS Institute, 2009).
19. Christopher Schenk and Richard Pollastro, *Natural Gas Production in the United States*, U.S. Geological Survey Fact Sheet FS-0113-01, January 2002, http://pubs.usgs.gov/fs/fs-0113-01/.
20. Gail the Actuary, "Arthur Berman Talks About Shale Gas," *The Oil Drum*, posted July 28, 2010, http://www.theoildrum.com/node/6785.
21. David Hughes study. Post Carbon Institute, in progress…
22. Richard Heinberg, *Searching for a Miracle: Net Energy Limits and the Fate of Industrial Societies* (International Forum on Globalization and Post Carbon Institute, 2009).
23. This conclusion is supported by P. Moriarty and D. Honnery, "What Energy Levels Can the Earth Sustain?" *Energy Policy* 37, no. 7 (July, 2009), 2469-2474. Abstract: "Several official reports on future global primary energy production and use develop scenarios which suggest that

the high energy growth rates of the 20th century will continue unabated until 2050 and even beyond. In this paper we examine whether any combination of fossil, nuclear, and renewable energy sources can deliver such levels of primary energy—around 1000 EJ in 2050. We find that too much emphasis has been placed on whether or not reserves in the case of fossil and nuclear energy, or technical potential in the case of renewable energy, can support the levels of energy use forecast. In contrast, our analysis stresses the crucial importance of the interaction of technical potentials for annual production with environmental factors, social, political, and economic concerns and limited time frames for implementation, in heavily constraining the real energy options for the future. Together, these constraints suggest that future energy consumption will be significantly lower than the present level."

24. Heinberg, *Searching for a Miracle*.
25. Heinberg, *Searching for a Miracle*, chapter 3.
26. This conclusion is largely supported by James H. Brown, *et al.*, "Energetic Limits to Growth," *Bioscience* 61, no.1 (January 2011), 19-26: "The bottom line is that an enormous increase in energy supply will be required to meet the demands of projected population growth and lift the developing world out of poverty without jeopardizing current standards of living in the most developed countries. And the possibilities for substantially increasing energy supplies are highly uncertain. Moreover, the nonlinear, complex nature of the global economy raises the possibility that energy shortages might trigger massive socioeconomic disruption."
27. "Drowning in Oil," *The Economist*, March 4, 1999.
28. International Energy Agency, *World Energy Outlook 1998* (Paris: IEA Publications, 1998), 78.
29. Chris Nelder, "World Will Soon Face an Oil Supply Crunch," *Energy & Capital*, posted September 18, 2009.
30. Richard Heinberg, "Goldilocks and the Three Fuels," *Reuters*, posted February 18, 2010.
31. James Hamilton, *Causes and Consequences of the Oil Shock of 2007*, Brookings Papers on Economic Activity, March 2009.
32. Joe Cortright, "Driven to the Brink: How the Gas Price Spike Popped the Housing Bubble and Devalued the Suburbs," White Paper, *CEOs for Cities*, 2008, http://www.ceosforcities.org.
33. Jad Mouawad, "For OPEC, Current Oil Price Is Just Right," *The New York Times*, September 9, 2009.
34. Jon Talton, "With Oil Prices Around $90, Recovery is Over a Barrel," *The Seattle Times*, December 9, 2010; David Murphy, "Further Evidence of the Influence of Energy on the U.S. Economy," *The Oil Drum*, posted April 16, 2009, http://netenergy.theoildrum.com/node/5304; Jeff Rubin, "We Have Run Out of Oil We Can Afford to Burn," *The Globe and Mail*, October 6, 2010; "Oil Price is Risk to Economic Recovery, Says IEA," *BBC News*, posted January 5, 2011; Derek Thompson, "How Oil Could Kill the Recovery," *The Atlantic*, posted January 6, 2011.
35. Cameron Leckie, "Economic Growth: A Zero Sum Game," *On Line Opinion*, posted November 25, 2010.