



# At \$100 Oil - What Can the Scientist Say to the Investor?

Posted by <u>Nate Hagens</u> on January 4, 2008 - 11:44am Topic: <u>Supply/Production</u> Tags: <u>biophysical economics</u>, <u>charles hall</u>, <u>eroei</u>, <u>eroi</u>, <u>investment</u>, <u>net energy</u> [list all tags]

The following post is my cut and paste review of a new paper by <u>Charles Hall</u>, Robert Powers, and William Schoenberg titled "*Peak Oil, Investments, and the Economy in an Uncertain Future*". This paper, along with 16 others (including 2 by theoildrum.com contributors), will be part of an upcoming book edited by Professor David Pimentel, "*Renewable Energy Systems: Environmental and Energetic Issues*". (I'll provide links when published). The paper by Professor Hall et al. is a thoughtful preliminary treatise on the impact that projected lower net energy for petroleum might have on the economy and investments.



The following graphics and grey box quotes are taken, in order, from the paper "Peak Oil, Investments, and the Economy, in an Uncertain Future". The paper is much longer than what is pasted below, but this post should give a general sense of the authors work. The comments between the grey boxes, as well as the conclusion, are my own:

While we are used to thinking about the economy in monetary terms, those of us trained in the natural sciences consider it equally valid to think about the economy and economics from the perspective of the energy required to make it run. When one spends a dollar, we do not think just about the dollar bill leaving our wallet and passing to some one else's. Rather, we think that to enable that transaction, that is to generate the good or service being purchased, an average of about 8,000 kilojoules of energy (equal to roughly the amount of oil that would fill a coffee cup) must be extracted from the Earth and turned into roughly a half kilogram of carbon dioxide. Take the money out of the economy and it could continue to function through barter, albeit in an extremely awkward, limited and inefficient way. Take the energy out and the economy would immediately contract immensely or stop.

Professor Hall also has recently written a textbook on Biophysical Economics, and the above example illustrates part of the difference between biophysical economics and neo-classical economics. There is no 'substitute' for energy. Conventional economists see economic activity as a function of infinite "money creation", rather than a function of finite stocks and flows. Though we are not taught this way, the economy is 100% dependent on available energy. (Biophysical economics is a step in the right direction, but does not address the *demand-side* problems with neo-classical economics -e.g. we are not rational utility maximizers, 'utility' itself being a scientifically non-measurable tautology, wants are not needs, neuromarketing CAN influence our decisions, etc.) Without a growing energy surplus, the *only* way we can have economic growth is by a)borrowing from environment, b)an increasing global GINI coefficient of wealth inequality, c)concomittant increases in efficiency and/or conservation. Otherwise 'increases' in GDP are just accounting tricks. When oil peaks (and probably before, due to net energy), *global* growth will be over. (I acknowledge several non-zero, but extremely low odds exceptions to this statement)

Cuba found this out in 1991 when the Soviet Union, facing its own oil production and political problems at that time, cut off Cuba's subsidized oil supply. Both Cuba's energy use and its GDP declined immediately by about one third, all groceries disappeared from market shelves within a week and the average Cuban lost 20 pounds.

I could use 2-2.5 of these energy crises...;) (There is also a movie "The Power of Community" about the successful response of Cuba to their oil crisis)

While the United States has become more efficient in using energy in recent decades, most of this is due to using higher quality fuels, exporting heavy industry and switching what we call economic activity, and many other countries, including efficiency leader Japan, are becoming substantially less efficient.

The very large use of fossil fuels in the United States means that each of us has the equivalent of 60 to 80 hard working laborers to "hew our wood and haul our water" as well as to grow, transport and cook our food, make, transport and import our consumer The Oil Drum | At 00 Oil - What Can the Scientist Say to the Investor?

goods, provide sophisticated medical and health services, visit our relatives and take vacations in far away or even relatively near by places. Simply to grow our food requires the energy of about a gallon of oil per person per day, and if a North American takes a hot shower in the morning he or she will have already used far more energy than probably two thirds of the Earth's human population use in an entire day.

A quibble~ this differs from the numbers I've been using. I've seen it several places that 1 barrel of oil has the amount of calories that equates to roughly 25,000 hours of human labor. Of course, me sitting at a computer will use less calories than my friend the jackhammer operator, but consider that as average. Working 50 weeks per year at 40 hours per week, that equates to 12.5 years of labor per barrel - each American uses 25 barrels+ of oil per year, which is 312 'hard working laborers', not 60. If we include gas and coal, the number is over 700 of these 'energy slaves'. (Professor Hall works *much* harder than I do, so if he meant 60-80 "Charlie Halls", I'll agree...;) I guess I need to track down a source for my 25,000 figure.

.... So our physical capacity to produce oil depends upon our ability to keep finding large oil fields in regions that we can reasonably access, our willingness to invest in exploration and development, and our willingness to not produce too quickly. The usual economic argument is that if supply is reduced relative to demand then the price will increase which will then signal oil companies to drill more, leading to the discovery of more oil and then additional supply. Although that sounds logical, the results from the oil industry might not be in accordance to that logic as the empirical record shows that the rate at which oil and gas is found has little to do with the rate of drilling.



Annual rates of total drilling for and production of oil and gas in the US, 1949-2005 (R2 of the two = 0.005; source: U.S. EIA and N. D. Gagnon). Since drilling and other exploration activities

This surprised me. I would have thought there was some stronger correlation than ZERO. Obviously a much better predictor of this years production, is last years production plus (2 years ago prod. minus last years production). Only around the peak would that have not had high predictive value. But I leave such details to <u>the experts</u>. The graphic is also potentially misleading in that it does not show discoveries of oil but production- some of those wells might have been drilled for different reasons than production (exploration, injection, etc.)

The United States clearly has experienced "peak oil". In a way this is quite remarkable, because as the price of oil increased by a factor of ten, from 3.50 to 35 dollars a barrel during the 1970s, a huge amount of capital was invested in US oil discovery and production efforts so that the drilling rate increase from 95 million feet per year in 1970 to 250 million feet in 1985. Nevertheless the production of crude oil decreased during the same period from the peak of 3.52 billion barrels a year in 1970 to 3.27 in 1985 and has continued to decline to 1.89 in 2005 even with the addition of Alaskan production.

In 2006, when oil averaged over \$60, there was a 20 year record of drilling feet. According to <u>API estimates</u>, 290 million feet were drilled in 2006 with over 74 million in the fourth quarter alone. But annual production declined to 1.86 billion barrels.

Energy return on investment (EROI or EROEI) is simply the energy that one obtains from an activity compared to the energy it took to generate that energy. The procedures are generally straightforward, although rather too dependent upon assumptions made as to the boundaries, and when the numerator and denominator are derived in the same units, as they should, it does not matter if the units are barrels (of oil) per barrel, Kcals per Kcal or MJoules per Mjoule as the results are in a unitless ratio. The running average EROI for the finding and production of US domestic oil has dropped from greater than 100 kilojoule returned per kilojoule invested in the 1930s to about thirty to one in the 1970s to between 11 and 18 to one today. This is a consequence of the decreasing energy returns as oil reservoirs are increasingly depleted and as there are increases in the energy costs as exploration and development are shifted increasingly deeper and offshore. Even that ratio reflects mostly pumping out oil fields that are half a century or more old since we are finding few significant new fields. (In other words we can say that new oil is becoming increasingly more costly, in terms of dollars and energy, to find and extract).

While we do not know whether that extrapolation is accurate, essentially all EROI studies of our principal fossil fuels do indicate that their EROI is declining over time, and that EROI declines especially rapidly with increased exploitation (e.g. drilling) rates. This decline appears to be reflected in economic results. In November of 2004 The New York Times reported that for the previous three years oil exploration companies worldwide had spent more money in exploration than they had recovered in the dollar

value of reserves found. Thus even though the EROI of global oil and gas is still about 20:1 as of 2007, this ratio is for all exploration and production activities. It is possible that the energy break even point has been approached or even reached for finding new oil. Whether we have reached this point or not the concept of EROI declining toward 1:1 makes irrelevant the reports of several oil analysts who believe that we may have substantially more oil left in the world, because it does not make sense to extract oil, at least for a fuel, when it requires more energy for the extraction than is found in the oil extracted.

This is a critical (and shocking) observation. So I can enjoy my weekend, I will assume the suggestion of energy break even for new oil is for the United States, and not the world. But I'm not sure hard data exists in either case, a fact Dr. Hall has pointed out and lamented. It is quite possible that energy break even is already occurring globally, at least for replacement costs (e.g. much of the 86 mbpd currently produced is using energy that was 'input' long ago. In this sense, global net energy decline is 'stealth' in nature.

\*\*Of course it could/will make sense to extract oil at energy break even or lower, if the energy we used to extract it was plentiful. But oil and natural gas are the primary fuels used to extract and refine, crude oil, so approaching energy break even would be an extremely fast treadmill for the economic system, as we will see below. It also suggests that the economy 'feels' the high EROI stuff which was found long ago, but that the 'yet-to-be-discovered' may not translate to 'yet-tobe-produced' due to high costs.

How well we weather this coming storm will depend in large part on how we manage our investments now. From the perspective of energy there are three general types of investments that we make in society. The first is investments into getting energy itself, the second is investments for maintenance of, and replacing, existing infrastructure, and the third is discretionary expansion. In other words before we can think about expanding the economy we must first make the investments into getting the energy necessary to operate the existing economy, and into maintaining the infrastructure that we have, at least unless we wish to accept the entropy-driven degradation of what we already have. Investors must accept the fact that the required investments into the second and especially the first category are likely to increasingly limit what is available for the third. In other words the dollar and energy investments needed to get the energy needed to allow the rest of the economy to operate and grow have been very small historically, but this is likely to change dramatically. This is true whether we seek to continue our reliance on ever-scarcer petroleum or whether we attempt to develop some alternative. Technological improvements, if indeed they are possible, are extremely unlikely to bring back the low investments in energy that we have grown accustomed to.

The main problem that we face is a consequence of the "best first" principle. This is, quite simply, the characteristic of humans to use the highest quality resources first, be they timber, fish, soil, copper ore or, of relevance here, fossil fuels.... It is critical for CEOs and government officials to understand that the best oil and gas are simply gone, and there is no easy replacement.

Perhaps that message is starting to be heard and understood by CEOs and government officials. The issue is that when they see a problem, they like to hear a solution. The solutions are difficult, complex and do not conform to the systems that put the CEOs and government officials in the positions they now hold.

We pay for imported oil in energy as well as dollars, for it takes energy to grow, manufacture or harvest what we sell abroad to gain the foreign exchange with which we buy fuel, (or we must in the future if we pay with debt today). In 1970 we gained roughly 30 megajoules for each megajoule used to make the crops, jet airplanes and so on that we exported. But as the price of imported oil increased, the EROI of the imported oil declined. By 1974 that ratio had dropped to nine to one, and by 1980 to three to one. The subsequent decline in the price of oil, aided by the inflation of the export products traded, eventually returned the energy terms of trade to something like it was in 1970, at least until the price of oil started to increase again after 2000. A rough estimate of the quantity and EROI of various major fuels in the U.S., including possible alternatives, is given in Figure 5.5. An obvious aspect of that graph is that qualitatively and quantitatively alternatives to fossil fuel have a very long way to go to fill the shoes of fossil fuels. This is especially true when one considers the additional qualities of oil and gas, including energy density, ease of transport and ease of use.



Figure 5.5. "Balloon graph" representing quality (y graph) and quantity (x graph) of the United States economy for various fuels at various times. Arrows connect fuels from various times (i.e. domestic oil in 1930, 1970, 2005), and the size of the "balloon" represents part of the uncertainty associated with EROI estimates.
(Source: US EIA, Cutler Cleveland and C. Hall's own EROI work in preparation)Click to Enlarge.

By quality here, on the y-axis, they mean EROI, as opposed to 'energy quality'. So EROI x Scale = Total energy gain. The "USA 2005" balloon should be a different color - as its a 'consumption', not an energy source. But note that it is 20% greater than the total photosynthesis for the entire country!

And this graph suggests an important story. Yes, I've increasingly heard about 10:1+ EROIs on new generation biofuel technologies that are 'pending'. This may or may not be true. But even if it is we have to multiply EROI X Scale. With oil, we are getting the energy content of 86 million barrels a day times 20:1, or whatever the current energy gain average is. Biofuels, even the ones that might attain high EROIs, will be limited in scale. The scale issue is less clear but still relevant for the other alt energy sources of wind, solar and nuclear.

The implications of all this is that if we are to supply into the future the amount of petroleum that the US consumed in the first half of this decade it will require enormous investments in either additional unconventional sources, in import facilities or as payments to foreign suppliers. That will mean a diversion of investment capital and of money more generally from other uses into getting the same amount of energy just to run the existing economy. In other words investments, from a national perspective, will be needed increasingly just to run what we have, not to generate real new growth. If we do not make these investments our energy supplies will falter or we will be tremendously beholden to foreigners, and if we do, the returns may be small to the nation, although of course if the price of energy increases greatly the returns to the individual investor may be large. Another implication is if this issue is as important as we believe it is then we must pay much more attention to the quality of the data we are getting about energy costs of all things we do, including getting energy. Finally the failure of increased drilling to return more fuel calls into question the basic economic assumption that scarcity-generated higher prices will resolve that scarcity by encouraging more production. Indeed scarcity encourages more exploration and development activity, but that activity does not necessarily generate more resources. It will also encourage the development of alternative liquid fuels, but their EROIs are generally very low.

What would be the impacts of a large increase in the energy and dollar cost of getting our petroleum, or of any restriction in its availability? While it is extremely difficult to make any hard predictions, we do have the record of the impacts of the large oil price increases of the 1970s as a possible guide. These "oil shocks" had very serious impacts on our economy which we have examined empirically in past publications (e.g. Hall et al. 1986). Many economists then and now did not think that even large increases in the price of energy would affect the economy dramatically because energy costs were but three to six percent of GDP. But by 1980, following the two "oil price shocks" of the 1970s, energy costs had increased dramatically until they were 14 percent of GDP.

### The Cheese Slicer Model

We have attempted to put together a conceptual and computer model to help us understand what might be the most basic implications of changing EROI on the economic activity of the United States. The model was conceptualized when we

examined how the U.S. economy responded to the "oil shocks" of the 1970s. The underlying foundation is the reality that the economy as a whole requires energy (and other natural resources derived from nature) to run, and without these most basic components it will cease to function. The other premise of this model is that the economy as a whole is faced with choices in how to allocate its output in order to maintain itself and to do other things. Essentially the economy (and the collective decision makers in that economy) has opportunity costs associated with each decision it makes. Figure 5.6 shows our basic conceptual model parameterized for 1970, before the oil shocks of that decade.



The "Cheese slicer" diagrammatic model, which is a basic representation the fate of the output of the U.S. economy, 1970. The box in the middle represents the U.S. economy, the input arrow from the left represents the energy needed to run the economy, the large arrow on the left of the box represents the output of the model (i.e. GDP) which is then subdivided as represented by the output arrow going to the right. In other words the economic output is "sliced" into different uses according to the requirements and desires of that economy/society. (Data principally from the U.S. Department of Commerce. Extrapolations via the Millennium Institute's T-21 model courtesy of Andrea Bassi)) Click to Enlarge.

The large square represents the structure of the economy as a whole, which we put inside a symbol of the Earth biosphere/geosphere to reflect the fact that the economy must operate within the biosphere. In addition, of course, the economy must get energy and raw materials from outside the economy, at least as narrowly perceived, that is from nature (i.e. the biosphere/geosphere). The output of the economy, normally considered GDP, is represented by the large arrow coming out of the right side, where the depth of the arrow represents 100 percent of GDP. For the sake of developing our concept we think of the economy, for the moment, as an enormous dairy industry and

cheese as the product coming out of the right hand side, moving towards the right. This output (i.e. the entire arrow) could be represented as either money or embodied energy. We use the former in this analysis (as almost all of the relevant data is recorded in monetary, not energy, units), but it is probably not terribly different from using energy outputs. So, our most important question is "how do we slice the cheese", that is how do we, and how will we divide up the output of the economy, or said differently, in what way can the output of the economy be divided up with the least objectionable opportunity cost. Most economists might answer "according to what the market decides," that is according to consumer tastes and buying habits. But we want to think about it a little differently because we think things might be profoundly different in the future.



*Figure 5.7.* Same as figure 5.6 but for 1981, following large increases in the price of oil. *Note change in discretionary investments.* Click to Enlarge.



Figure 5.8. Same as figure 5.6 but for 2007, following large decreases then small increases in the price of oil. Not change in discretionary investments. Click to Enlarge.



Figure 5.9. Same as figure 5.6 but for 2030, with a projection into the future with the assumption that the EROI declines from 20:1 (on average) to 10:1. **Click to Enlarge**.



The results of our simulation suggest that discretionary income, including both discretionary investments and discretionary consumption, will move from the present 50 or so percent in 2005 to about 10 percent by 2050, or whenever (or if) the composite EROI of all of our fuels reaches about 5:1.

As 'new oil' replaces 'found oil', the EROI will drop faster than the global decline rate. In this sense, the authors time estimate (2050) for the contraction of discretionary spending might be (*extremely*) conservative as there is evidence already of a crowding out of non-energy sectors. Further study combining net energy with global decline rates is urgently needed, especially as the worlds last giant oil fields deplete, we will be replacing them (if we're lucky), with newer, more expensive (in energy and dollar terms) production. Who knows how high of energy gain Ghawar has provided the world - 200:1? 1000:1??? Impossible to tell because we don't have the data. Another insight is the difference between 'fixed' vs. 'marginal' EROI. As oil wells and infrastructure were created in era of cheap fuel, they continue to produce high return oil. What would be the EROI of this oil if it had to be rebuilt now? (Eg. how many stripper wells in GOM remain profitable but if damaged by hurricane aren't repaired because marginal cost is too high?)

The above sensitivity analysis from 2007 to 2050, were it to be done in 'dollars', would likely not show this decline in discretionary income for society. Deep seated assumptions about technology, capital and efficiency improvements, combined with the unlimited support of central bank fiat currency, would underestimate the shrinkage in discretionary investment, especially if conflated perceptions between the 'actual production' and 'productive capacity' of oil persist. Such an analysis would likely also fall victim to the phenomenon of 'receding horizons', as tar sands, deep

water oil, etc. might look slightly profitable at \$90+ oil but when oil is at \$150, they will STILL only be slightly profitable as the inputs will have also increased in price. This 'running in place' is the real world manifestation of a low energy gain technology, and why biophysical analysis is important.

Individual businesses would be affected by having their fuel costs increase and, for many, a reduction in demand for their products. This simultaneous inflation and recession happened in the 1970s and is projected to happen into the future as EROI for primary fuels declines. The "stagflation" that occurred in the 1970s was not supposed to happen according to an economic theory called the Phillips curve. But an energy-based explanation is easy (e.g. Hall 1992). As more money was diverted to getting the energy necessary to run the rest of the economy disposable income, and hence demand for many non-essential goods and services, declined, leading to economic stagnation. Meanwhile the increased cost for energy led to inflation, as there was no additional production that occurred from this greater expenditure. Although unemployment increased overall during the 1970s it was not as much as demand decreased, as labor at the margin became relatively useful compared to increasingly-expensive energy. Individual sectors might be much more impacted as happened in 2005, for example, with many Louisiana petrochemical companies that were forced to close or move overseas when the price of natural gas increased. On the other hand alternate energy businesses, from forestry operations and woodcutting to solar devices, might do very well.

#### So what can the scientist say to the investor?

When the price of oil increases it does not seem to be in the national or in corporate interest to invest in more energy-intensive consumption, as Ford Motor Company seems to be finding out with its large emphasis on large SUVs and pickup trucks. We are likely to have over invested already in the number of remote second homes, cruise ships, and Caribbean semi-luxury hotels, so that it may not a particularly good idea to do more of that now. This is due to the "Cancun effect" - that such hotels require the existence of large amounts of disposable income from the US middle class and cheap energy, even though that disposable income that may have to be shifted into the energy sector with less of an opportunity cost to the economy as a whole. Investors who understand the changing rules of the investment game are likely to do much better in the long run.

So what can the scientist say to the investor? The options are not easy. As noted above worldwide investments in seeking oil have had very low monetary returns in recent years. Investments in many alternatives may not fare much better. Ethanol from corn projects are financially profitable to the individual investor because they have been highly subsidized by the government, but they are probably a poor investment for the Nation. It is not clear that this fuel makes much of an energy profit, with an EROI of 1.6 at best, and less than one for one at worst, depending upon the study used for analysis. Biodiesel may have an EROI of about three to one. Is that a good investment? Clearly

not relative to remaining petroleum, but some day as petroleum EROI declines it may be. However real fuels must have EROIs of 5 or 10 or more returned on one invested to not be subsidized by petroleum or coal in various ways, such as the construction of the vehicles and roads that use them. Other biomass, such as wood, can have good EROIs when used as solid fuel but face real difficulties when converted to liquid fuels, and the technology is barely developed.

This is the issue of energy quality, which cannot be ignored due to how embedded liquid fuels are in our transport system, hence total economic system. Even though electricity currently is a higher quality fuel than oil, that may change as attempts to turn all sort of disparate BTU sources into transportation fuel may occur (Fischer-Tropsch Coal-to-liquids, biodiesel, ethanol, etc.) So EROI and scale are important, but so is quality, which is determined by what is needed and desired by society.

The scale of the problem can be seen by the fact that we presently use more fossil energy in the US than is fixed by all green plant production, including all of our croplands and all of our forests. Biomass fuels may make more sense in nations where biomass is very plentiful and, more importantly, where present use of petroleum is much less than in the US. Alternatively one might argue that if we could bring the use of liquid fuels in the United States down to, say, 20 percent of the present than liquid fuels from biomass could fill in a substantial portion of that demand. Nevertheless we should remember that historically we in the U.S. have used energy to produce food and fibre, not the converse, because we have valued food and fibre more highly. Is this about to change?

# Apparently, <u>yes</u>.

Energy return on investment from coal is presently quite favourable compared to alternatives (ranging from perhaps 50:1 to 100:1), but the environmental costs are probably unacceptable as the case for global warming and other pollutants from coal burning becomes increasingly clear. Injecting carbon dioxide into some underground reservoir seems unfeasible for all the coal plants we might build, but it is being pushed hard by many who promote coal. Nuclear has a debatable moderate energy return on investment (5-15:1, some unpublished studies say more), but newer analyses need to be made. Nuclear has a relatively small impact on the atmosphere, but there are large problems with public acceptance and perhaps safety in our increasingly difficult political world.

Windmills have an EROI of 15-20 return on one invested, but this does not include the energy cost of back up or electricity "storage" for periods when the wind is not blowing. They make sense if they can be associated with nearby hydroelectric dams that can store water when the wind is blowing and release water when it is not, but the intermittent release of water can cause environmental problems. Photovoltaics are expensive in dollars and presumably energy relative to their return, but the technology is improving. One should not be confused by all claims for efficiency improvements because many require very expensive "rare-earth" doping materials, and some may

become prohibitively expensive if their use expands greatly. According to one savvy contractor the efficiency in energy returned per square foot of collector has been increasing, but the energy returned per dollar invested has been constant as the price of the high end units has increased. Additionally while photovoltaics have caught the public's eye the return on dollar investment is about double for hot water installations. Windmills, photovoltaics and some other forms of solar do seem to be a good choice if we are to protect the environment, but the investment costs up front will be enormous compared to fossil fuels.

The authors allude to, but do not explicitly say, that Peak Oil may initiate a "Tragedy of the Investing Commons". Short-term (3-5 years) high returns can be made by entrepreneurs and corporations by using both government subsidies (in the case of ethanol) and societal subsidies (in the case of roads, hospitals, food, etc.) that only exist due to cheap transport fuels. Decisions that may look promising from a corporate boardroom perspective, would not look good from a global declining EROI perspective. So, investments in 'moderate' EROI technologies might pay off for individuals, while simultaneously the global energy gain cushion continues to drop. (But I guess this has been happening for a long time wrt the environment)

# CONCLUSION

It seems obvious to us that the U.S. economy is very vulnerable to a decreasing EROI for its principle fuels, whether that comes from an increase in expenditures overseas if and as the price of imported oil increases more rapidly than that of the things that we trade for it, or as domestic oil and gas reserves are exhausted and new reservoirs become increasingly difficult to find, or as we turn to lower EROI alternatives such as biodiesel and or photovoltaics. We do not know exactly what all this means, but our straightforward model suggests that a principal effect will be a decline in disposable income and a greater requirement for getting energy, with all the economic impacts that entails. Since more fuel will be required to run the same amount of economic activity the potential for environmental impacts increasing is very strong. On the other hand protecting the environment, which we support strongly, may mean turning away from some higher EROI fuels to some lower ones. We think all of these issues are very important yet are hardly discussed in our society or even in economic or scientific circles.

# **Concluding Thoughts**

As many in the Peak Oil aware community know, Charlie Hall has been researching and writing about energy for almost 30 years, initially as a graduate student of the late systems ecologist Howard Odum. I posted excerpts from this paper because I believe the implication of declining net energy is the single largest overlooked supply side phenomenon about oil and gas depletion, both on Wall St and on Main St. As 'best first' becomes 'best available now', more energy will be diverted to the energy sector, and as the authors have pointed out, this means less for productive society. This doesn't happen while everything stands still - the primary allocation mechanism for lower net energy is already underway -higher prices - squeezing less developed countries, less profitable businesses, less traveled air routes, etc. A secondary mechanism of declining net energy is negative economic growth resulting in global recession/depression, reducing energy prices and pulling the marginal EROI processes offline, many of them forever.

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However, there are many problems with EROI analysis, not the least of which is the difficulty of parsing non-energy limiting inputs, like water, soil, or knowledge, into energy terms. Its just simpler to denominate everything in dollars, and of course that is what has happened gradually, but nearly completely, over the last 3 decades. Net energy analysis also has the problem of correctly adjusting for energy quality, as all kilojoules are not created equal, nor do they stay equal in preferences/needs of a civilization. (did the Yibali tribesman 5 centuries ago in Saudi Arabia care about light sweet Arabian crude? No - they cared about strong Arabian horses). Net energy analysis is not a surgical tool, but more like a blunt instrument. But what EROI lacks in precision, it makes up for in scope. It at least attempts to ground analysis based on first principles - we need energy to procure more energy - to procure more dollars, we just print them (using paper, ink and energy).

The battle between the financial economy and the biophysical economy is seeing its first serious skirmish, as oil flirts with \$100, pricing out someone, somewhere. Somehow, more analysis like this one by Hall et al. need to be examined, understood and advanced. Grounding supply side analysis in physical terms is not easy, but it will ultimately be more accurate and a better predictor of the future on a planet with finite stocks and flows. I give great credit to the authors and their academic peers who continue to think about the world in this way. Limited funding, limited data and limited government interest, are prohibiting scientists like Prof. Hall from accomplishing more than just nibble around the edges of this vital topic. Finally, though net energy analysis is an important tool, it is still a part of the larger science that is essentially just a 'documentation' of natural resource depletion and the environmental entropy process. Until we thoroughly address the demand side of our energy consumption, better and more correct energy analyses cannot be optimized.

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