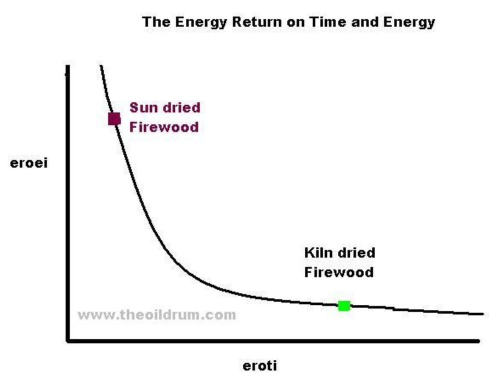
The Energy Return on Time

Posted by Nate Hagens on July 25, 2007 - 11:07am
Topic: Alternative energy
Tags: demand, discount rates, efficiency, eroi, just-in-time, net energy, sustainability, time [list all tags]

While writing the recent piece on home heating, I was surprised to calculate many different numbers for the energy return on firewood. Though the outputs were only slightly different in quantity of BTUs, there was a wide range of inputs. But the primary reason for the return disparity was the presence of the market economy - those processing firewood for their own use had higher energy returns than those selling wood for profit - the accelerated drying time to process large amounts of wood required an additional wood input which dropped the energy return. Graphically this showed up as a tradeoff between maximizing energy return on TIME versus maximizing energy return on ENERGY. This reminded me that energy return is not a hard-and-fast principle, and also that society, obviously, will optimize its resources based on what it perceives to be its most limiting input(s). However, in an upcoming world constrained by energy, or any limiting variable other than time/money, we can increase our energy available by reducing the return on other inputs, such as time.

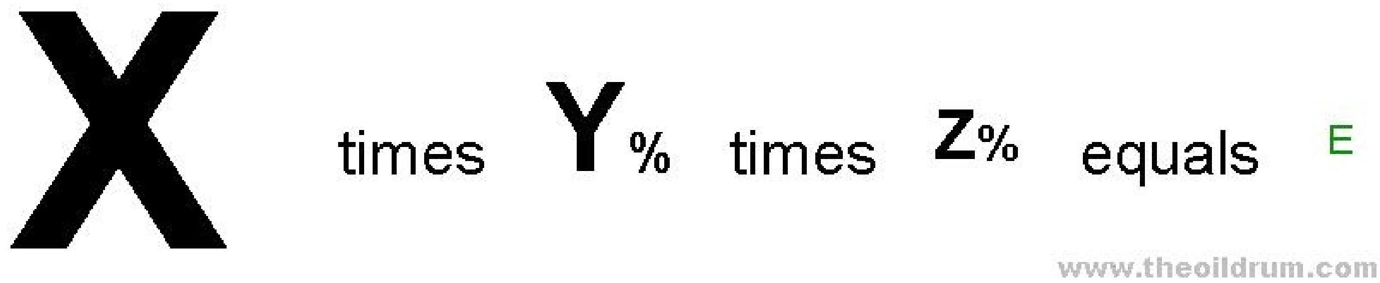


INTRODUCTION - A COMMON FRAMEWORK

I've written several articles here related to net energy:

"Using Hubbert Method on EIA Data - The Tiger Chasing its Tail?"
"A Net Energy Parable -Why is EROI Important?"
"Energy From Wind - A Discussion of the EROI Research"
"Ten Fundamental Principles of Net Energy"
"Peak Oil - Why Smart Folks Disagree - Part II"

Since my thinking and research has changed a bit recently, I'd like to first take a big step back and attempt to simplify things, before moving on to a discussion on energy and time. The post ended up being longer and denser than intended, but I believe it gathers momentum as it goes, like a fallen sasquatch on a ski slope.



Humans use exosomatic energy - we use more energy than our own body can store. We procure this energy from a variety of sources and build infrastructure to harness and deliver it all around the planet. But other than drying our hair and laundry in the sun/wind, most of this energy needs to be found/harnessed/refined and distributed to a new or existing societal infrastructure to be able to provide us with its energy services.
We can measure (or at least estimate) in BTU terms, the planets numerous energy 'capital accounts'. Some stores of energy, like light sweet crude oil are awesome in their energy density and versatility and there is, (or once was) a great deal of them. Other energy sources, like wind via wind turbines, are also impressive in the energy they provide, but it is of a different nature - diffuse, intermittent and renewable. Just like we don't really care about dollars but instead what they buy for us, we don't especially care about energy per se, but rather the energy services it provides. Once we pay for the harnessed energy, how we use it is almost as important as how expensive it was to procure.

SUPPLY AND DEMAND WITH A TWIST

Energy allows us to do work. More energy allows us to do more work (i.e. grow). Societies energy profit from one period to the next, is the sum total of all the harnessed energy itself, less the amount we needed to use to deliver this energy to a socially desirable form. We then have to subtract the amount we waste in its consumption to arrive at whats left -this small fraction is the amount actually *used* to produce human utility - lets call this E. Let's call the former 3 pieces X, Y and Z respectively. So our entire energy supply snafu can be simplified into X (the energy), Y, the efficiency of harnessing it, and Z, the efficiency of using it. If we cut X (the energy) in half, we can still arrive at the same E by doubling either Y (the efficiency/technology through which we harness the energy) or Z, (the efficiency with which we use the energy). While the Peak Oil problem is mostly specific to liquid fuels, the broader energy problem facing the growth economy is how to maintain/increase E, or be happier/generate the same or greater utility from a smaller E (energy used).

Here at theoildrum.com and other circles discussing our energy future, all things energy basically fall into those 4 areas:

X What is and how big is the energy source? (Actually, X is the sum of all energy sources, x1 (coal), x2(oil)....+xn = X)
Y How efficiently do we harness the energy? (what % of each x gets to the energy service side, after subtracting out energy costs?)
Z How efficiently do we use the harnessed energy in our infrastructure and human systems?
E This is the energy that's actually 'used' after all heat losses have been subtracted. What do we use energy for? Why is it important?

My main points in presenting energy in this framework are 1) X is what it is, and will not change meaningfully on any human time scale unless it is consumed, 2) decreasing Y% and Z% (becoming more efficient at both harnessing or using X) are identical in their impact on E, 3)Though there are physical limits on X, Y and Z, there are none on E, in either direction (except perhaps minimum trophic levels of caloric consumption).

Now that we've dispensed with the energy-world-according-to-Nate, lets move on towards the meat of the post:

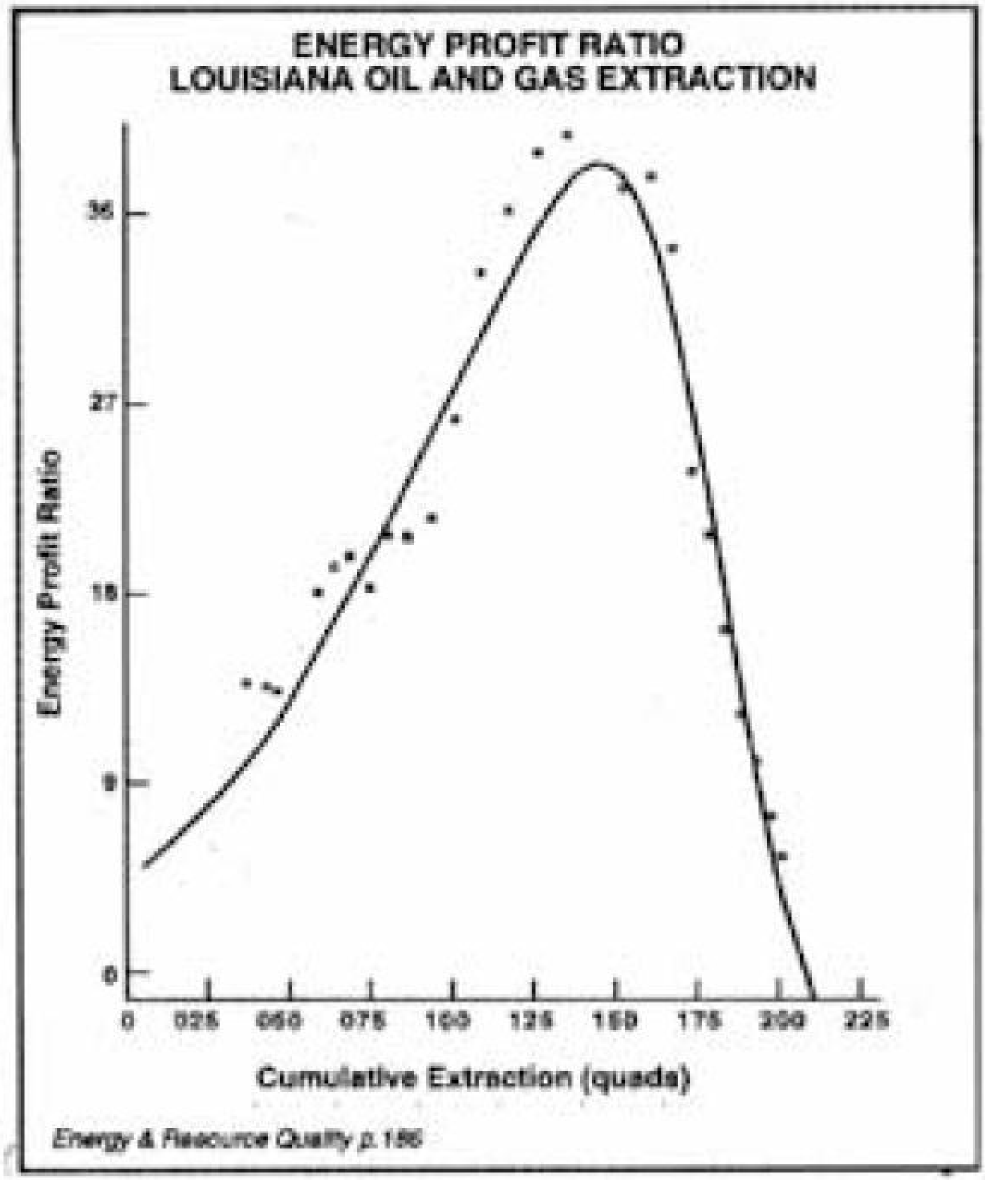
A REFRESHER ON NET ENERGY ANALYSIS AND ENERGY RETURN ON INVESTMENT

One method for evaluating alternative energy systems is net energy analysis, which seeks to compare the amount of energy delivered to society by a technology to the total energy required to procure that energy to a socially useful form. Biophysically minded analysts prefer net energy analysis to standard economic analysis because it assesses the progression in the physical scarcity of an energy resource, and therefore is immune to the effects of market imperfections that distort monetary data. Also, because goods and services are produced from the conversion of energy into utility, net energy is a measure of the potential to perform useful work in social/economic systems.

Energy Return on Investment (EROI) is an oft-confused controversial but important subset of net energy analysis. EROI is basically a combined measure of how high of quality/density the original energy source is with the energy cost that the composite of harvesting technologies uses to deliver the energy to the consumptive stage. It is often confused because analysis crosses back and forth between 'Y' and 'Z' in the introductory graphic. (Google Robert Rapier and Vinod Khosla...;) EROI is strictly a measure of energy and its 'harvesting' costs in energy terms, not the efficiency of its use or it's transformation to another energy vehicle. For example, once coal is procured out of the ground at a particular energy return, the decision, and subsequent efficiency loss to turn it into electricity or Fischer-Tropsch diesel, are both part of Z, the consumption whims of society. Each energy technology (e.g. in situ mining for tar sands) is a composite of X and Y in the above graphic - a combination of the density/BTU caliber of the energy source and how much energy it takes to procure it to a useful form.

Combining everything then, **x times y** for each energy technology (oil, coal, solar, nuclear, etc) gives us the net energy, (or energy surplus) for each of earths energy sources. Add all these together and we get **X**, which is the current planetary energy resource. Multiply them by Y, and we have how much energy is available for human use. X times Y changes over time, as the race between depletion of high quality stocks/flow sites versus better technology unfolds.

Below is a graphic of the peaking and declining of EROI for Louisiana oil and gas production. Its very similar to an actual production curve - as production peaked and declined, net energy also declined sharply (fortunately we had 49 other states and 50+ other countries to get oil from when this occurred)



Lousiana EROI Profile - Source *"Energy and Resource Quality - The Ecology of the Economic Process"*, Hall, Cleveland and Kaufman, 1986

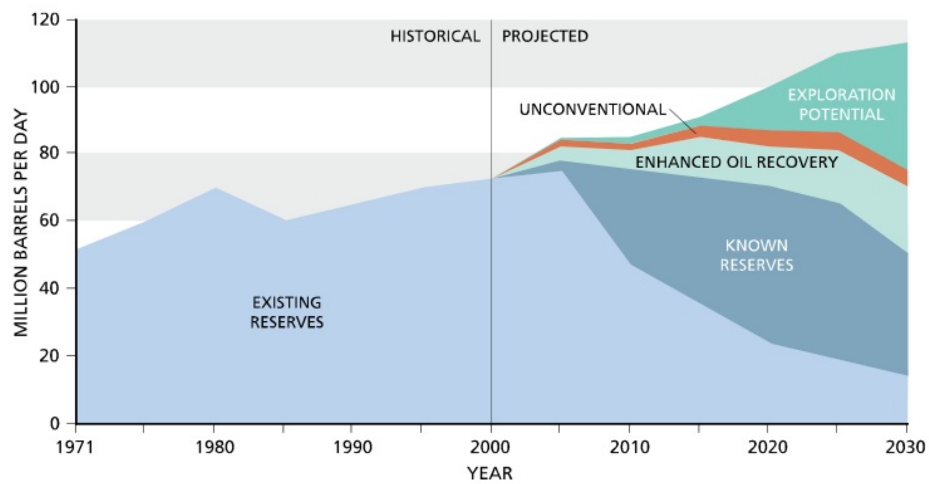
EROI is an important concept because we live on a finite planet ruled by physical systems subject to entropy. There is only so much low entropy energy present in fossil fuel stocks and solar/tidal flows that can be accessed at a meaningfully positive energy return. If society collectively becomes dependent on a certain aggregate energy gain system and attempts to replace it with a lower energy gain portfolio, keeping all other inputs equal, then a larger % of societies resources (labor, capital, etc) would have to be devoted to energy procurement, leaving less available for hospitals, infrastructure, and bowling, etc. EROI has a trade-off with scale - at low scale, EROI can be very high - at higher and higher scale sizes, EROI eventually declines. What society actually uses is EROI x Scale, which equates to the energy surplus (or net energy). If EROI x Scale of all energy sources declines from year to year, all the dollars in the world can't produce the energy gap that has been created. The missing energy would have to come from efficiency, conservation or demand destruction. A numerical example of a hypothetical society facing declines in net energy can be read here.

There are however, many problems with basing energy decisions solely or primarily on EROI. First, as will be seen below, it is not as physical a number as some would like to believe. Second, it has to be adjusted for societies choice of energy quality and this adjustment makes it follow the dictates of the market, something it was designed to look beyond. Third, any collapse-like implications of lower EROI from a societal perspective are not set in stone - lower system wide

EROI *could* be trumped by higher efficiency or new technologies on the consumption side, at least in theory. Fourth, an EROI figure, either high or low, doesn't tell us about the potential size nor of the timing of the alternative energy technology -my potato crop this year will probably be in excess of 50:1 EROI, but it will only help myself and my neighbors because my entire crop is about 50,000 BTUs worth of potatoes - or about 1/2 gallon of gasoline equivalent. Also, unless one parses environmental impacts into energy terms (which is doable but not at all accurate), EROI (currently) still fails to quantify undesirable energy externalities like increased pollution or ecosystem degradation. Finally, it gives us a narrow metric (though certainly broader than dollars) on *one* limiting variable (energy) that we may be facing in the future. Energy is probably the most important variable I can think of that propels global society forward, but water, soil, ecosystem services, and greenhouse gas emissions also may play a role in societal functioning at some future date.

Onward..

SIDEBAR - NET ENERGY AND NATIONAL PETROLEUM COUNCIL FORECAST



Illustrative Total Liquids Supply. Source: Figure ES-5 of NPC report Executive Summary.

There was not a single mention of net energy in the NPC report released last week. Perhaps the reason that oil companies don't use net energy in normal parlance is that it's really an ecological concept, and not (yet) congruous with the market system. True, if there *were* unlimited other high quality energy dense resources that comprised societies "**X**", then oil agencies could reasonably exclude the 'net' from their analysis. As it is, oil is ubiquitous in allowing every aspect of the global capitalist system to flourish. It can be replaced, but so far only by lower energy return liquid fuels or by changing the massively entrenched oil dependent transport infrastructure.

Net energy doesn't have much meaning at the company level. An oil company CFO doesn't say "Joe, I think we have declining EROI on our oil fields - what should we do?" He says - "We have accelerating cost pressures in finding new oil-should we even be drilling for that oil if its costs us $50 a barrel?". From a companies perspective, one looks at the dollar cost of accessing and delivering future production - the more difficult to access fields of the future will likely require more energy, and thus higher prices. This is an economic analysis. But when looked at from a societal perspective, while dollars are certainly important, another phenomenon emerges with declines in the net energy available. If the aggregate of the energy producing (harvesting) sector requires more energy due to depletion of the 'easy' portions of a resource, this energy *has* to come from what once went to non-energy sectors. So what the NPC is missing in the above graph, is that the projected 'growth' in oil supply will, especially the categories of ethanol, biofuels, tar sands, oil shale, etc. free up much less energy to non-energy society per barrel produced than the original, already used, high EROI oil. Essentially, can we assume that the 100+mbpd shown in 2030 would (if it were actually achieved) still free up the same % of oil and gas to society as it does now? More, or less? If less, then which currently productive sectors of the economy will this energy come from (electricity, natural gas and oil products)? Are agencies like the NPC responsible for this type of analysis? If not, then who is?

THE ENERGY RETURN OF FIREWOOD

Ok. Sorry for the long preamble. We now arrive at the central point of this post, which is that energy, due to human decisions on their inputs to Y and use of Z, is perpetually in a tradeoff with time. Recently, an oildrum post showed the potential scale of the forests in the United States were they to be used for heat/firewood. This analysis was 'gross' and did not take into account how much energy it would require to harvest and transport all the wood. While we are in reality not going to accomplish or even attempt this (I hope not), I learned many things from working through the numbers.

THE ANALYSIS

I interviewed 7 firewood 'experts' (Thanks to Hans, Gene, Lynn, Oildrum readers Vtpeaknik and Johnwilder, Whitey and my father), (I consider my father an expert...;) who have been harvesting repeatedly for a number of years - 2 were 'professional' firewood vendors (one in WI, and one in VT) and the other 4 procured the wood themselves for their own use in WI, VT, ME and AK. The energy needed to get firewood is a) to chop down the tree b) to buck it up into transportable pieces, c)to tranport it to the place where it will be d)split and e)dried (green wood has too high of moisture content to burn). Finally, f)it had to be transported again to its final place of consumption.

I came up with a range of EROIs for firewood from 7:1 to 100:1. Yes, thats what I thought - how could something with an equivalent energy output have such disparate energy returns? The math for 2 of the study cases is below:

Example 1 - Gene in Maine
Per Cord
Chainsaw - 3/8 gallon gasoline.
Splitter - 1/2 gallon of gasoline.
Gene uses horses to deliver the wood from the forest to his 'factory'
Feed for the horses (an indirect energy requirement) is also procured by horse/human labor
Wood is air dried from Jan-Feb to September when its delivered (time input 9 months)
Saw rig and conveyor to load in truck for transport to customers- 7/8 gallon of gasoline.
Total loaded in truck - about 1 3/4 gallons of gasoline.
Truck carries one cord and gets 10 mpg.
(I assumed average customer is 5 miles, so 1 gallon round trip)
Time input 8 hours per cord, plus 1 hour for equipment maintenance and 1 hour for horses
or 10 hours of labor per cord
Energy input per cord delivered 2.75 gallons x 115,000 BTU = 316,250 BTUs
Energy output per cord of mixed, dried hardwood = 20,000,000 BTUs
EROI of this particular firewood operation =20,000,000 / 316,250 = 63.25

Note, this does not include the energy inputs into the making of the saws and truck, the food requirements of the horses or Gene, or any of the maintenance of the roads used, or any other 'wide boundary' analyses. (that would be more correct but a heck of a lot of work)

Example 2 - Lynn in Vermont
Buys wood from firewood jobbers - 1/2 gallon per cord for chainsaw
Wood transported average of 5 miles to his firewood company (.5 gallon)
1/2 gallon for splitter
To kiln dry the wood (and have a 5 day turnaround time, year round)
Lynn uses 1 unit of 'crap wood' for each 8 units of salable firewood
Average customer distance for the 2,000+ cords per year - 20 miles but his truck holds 2 cords so 2 gallons round turn
Labor estimate 3 hours per cord
Time estimate - turnaround time 1 week
Energy inputs 4 gallons x 115,000 BTU
1/8 cord of wood =1/8 X 20,000,000 =2,500,000
Energy output = 20,000,000 per cord
Energy input = 3,075,000
EROI of firewood operation #2 = 20,000,000/ 3,075,000 = 6.75

The other 5 people I interviewed had a variety of similar inputs and their EROI calclulation ranged from 18:1 to 100:1 (the 100:1 was a person who chopped the wood by hand and required 52 hours per cord of labor).

Takeaways:

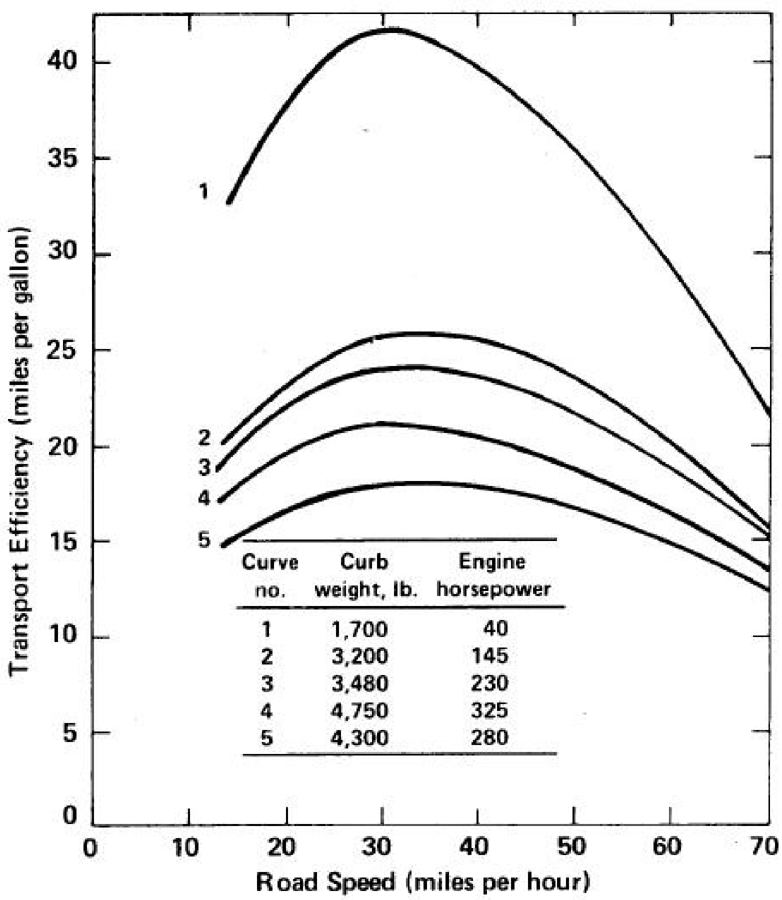
Clearly there are tradeoffs in the procurement of firewood between time, labor and energy. To mass produce, or to do things in a hurry (for reasons other than mass producing), using part of the lower quality scrap wood to quickly dry the wood reduces the energy return but increases not only the profit margin but the **EROTI (Energy Return on Time Invested)**. Alternatively, using extra time and the 'free' drying heat of the sun dramatically increases the energy return but gives a lower return on both labor and EROTI. While this example may be unique to this particular subset of **X** (forest biomass), we see this phenomenon as well in oil production. Bottlebrush extraction, horizontal well drilling and other new technologies access more parts of an oil field simultaneously, at a higher energy cost, in order to bring them to market faster than traditional slower methods. I don't have ready access to this data, but presumably we could increase the EROI of oil or at least stem the decline from over 100:1 in 1930 down to 10-20:1 earlier this decade (anecdotally this has dropped even further of late in the US), were we to suck on the straw a little slower.

TIME AND ENERGY ALSO HAVE TRADEOFFS ON THE CONSUMPTION SIDE

"But the rate at which new energy technologies, especially conservation, will in fact be introduced will depend on how we perceive the trade-off between time and other resources, and our sophistication and understanding of the new technologies. Thus a conservation measure doesn't happen automatically: it happens only if the economic penalties imposed by not conserving outweigh, in the individual's perception, the loss of time that the conservation measure entails; or if the individual can be persuaded to take a view of the future that is long range enough to justify his investing in the additional capital equipment necessary to save energy over the long run".(4) Alvin Weinberg, 1979

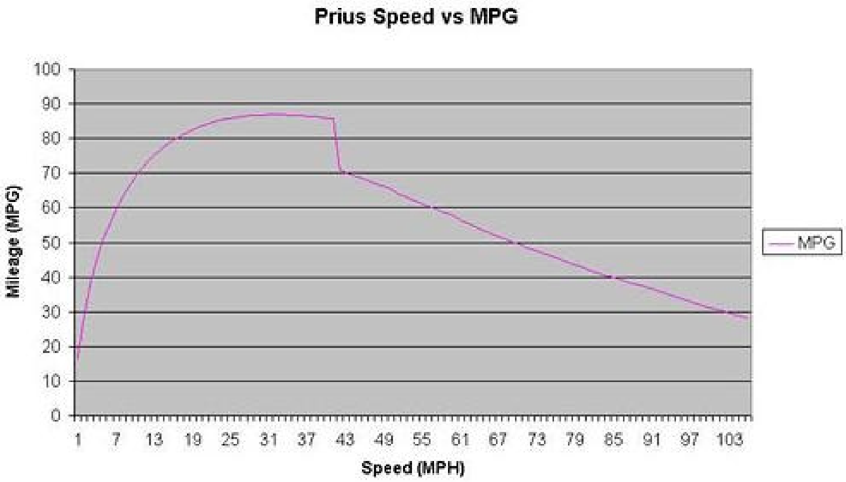
Once in the consumers control, energy again undergoes entropy, going from a low entropy high value substance that is paid for with money, to a high entropy, low value heat waste product (e.g. at 10-15% efficiency, 80-85% of the energy used in the internal combustion engine of an automobile is dissipated as wasted heat). Overspeeding, overlighting, overdrying, overlighting are all examples of how the average efficiency of our energy use declines.

As the introductory graphic explained, a high energy gain technology/energy source means we can be more profligate with how we spend energy. Similarly a lower energy gain system, especially compared to what we've built our infrastructure around, will require high energy gain substitutes, or corresponding increases in efficiency of the energy services we use for human utility. Time also impedes the 'efficiency' with which we use energy. One example that everyone is familiar with is driving. To get the most mileage per gallon, we would have to drive at speeds at or below the speed limit, depending on the size/type of car we are driving. Very low speeds don't generate enough force to overcome engine baseline and idle, very high speeds get us to where we are going faster, but at a cost of using considerably more energy.



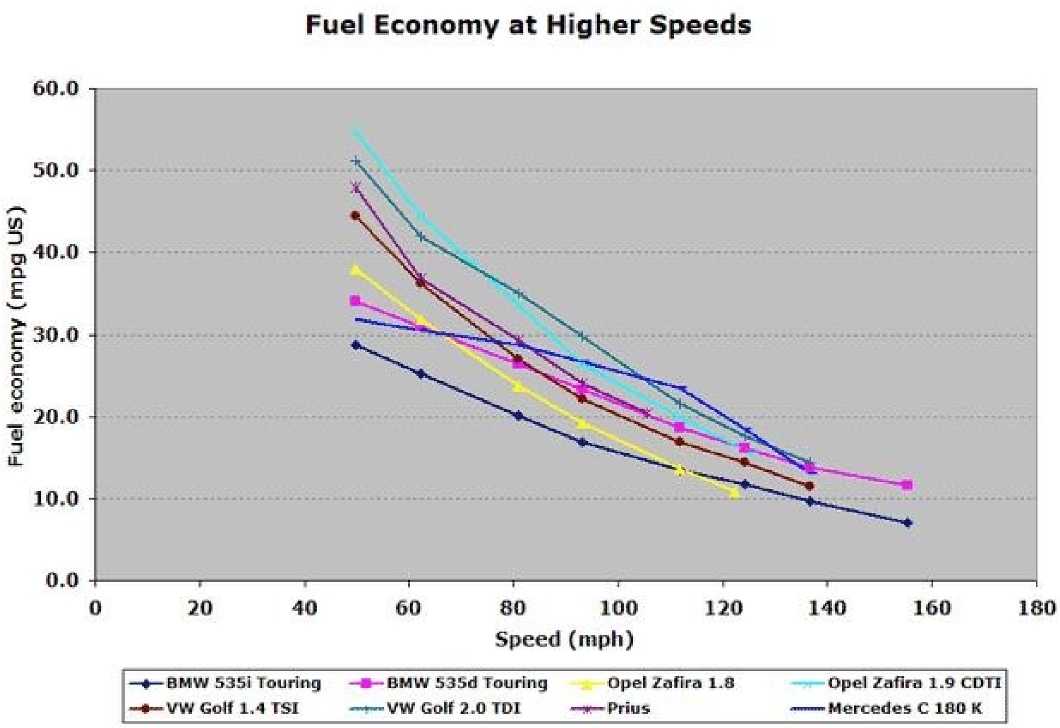
The tradeoff between time and energy in gas mileage of various size automobiles
D. Spreng "Time, Information and Energy Conservation" (2) (Click to Enlarge)

Here is a calculated example on an electric car (Prius) with values based on 68F, at sea level, with no A/C or wind.



The maximum return on energy for this car is at 32 mpg. (The maximum return on time would be as fast as one could safely drive.) The electric assist appears to help up to around 42 mph, at which point the engine starts to spin up, and mileage quickly falls off a cliff, and then continues to decrease more gradually as speed rises. (The shape of the graph could also only have come from a car with a continuously variable transmission - other than the transition where the internal combustion engine spins up, there are no obvious "steps" in the plot.) (source)

For most cars, a sharp dropoff in 'energy return' (which we usually call engine efficiency), starts at around 40-50 mph.



(Source)

Interestingly, going 50 mph gets twice the gas mileage (roughly) as going 100 mph. So its takes twice as long to get there but costs 1/2 as much.

THE MAXIMUM POWER PRINCIPLE

It is no surprise that people want to optimize their return on time, especially when a) energy and other basic requirements are currently cheap and b) we have a genetic propensity (amplified by culture) to steeply value the present over the future. The market optimizes dollars, via positive interest rates (which are based on time). If one has more time, one can effect more iterations of a money making process.

The tradeoff between time and energy is consistent with but slightly different than Lotka's and Odum's Maximum Power Principle, which states that organisms and ecosystems arrange themselves not by *efficient* energy use but by the *maximum rate*flow* of energy they can harness from the surrounding environment. Some even claim this organizing principle is the 4th law of thermodynamics. Late Tuesday night, I've decided the parallels of time/energy with the maximum power principle will require a subsequent post, (adding it to the list) but the fact that maximum power is achieved through the compromise between speed and efficiency of energy conversions at intermediate efficiencies is a well known biological concept(6). It's quite possible that the market, in a culture of resource extraction is the ultimate vehicle to pursue maximum power - power being represented by status which is currently correlated with dollars in digitized storage. However, I did find a fascinating paper, "On Ungulate Foraging Strategy - Energy Maximizers or Time Minimizers" which disputes some of the earlier ecological work asserting that animals maximize on power/energy. This study showed that bison, a prey animal, do in fact choose to optimize time, rather than energy intake, presumably to have more of their day to pursue other fitness increasing events (watching out for predators and finding really attractive bison). Clearly there are evolutionary forces that draw organisms to choose between energy maximization and time maximization - to me this seems like fertile ground for more research (if there is time...;)

> Eighth, in a compelling harmony with all the above thoughts we should cure ourselves of what I have been calling "the circumdrome of the shaving machine", which is to shave oneself faster so as to have more time to work on a machine that shaves faster so as to have more time to work on a machine that shaves still faster, and so on ad infinitum. This change will call for a great deal of recanting on the part of all those professions which have lured man into this empty infinite regress. We must come to realize that an important prerequisite for a good life is a substantial amount of leisure spent in an intelligent manner." Nicolai Georgescu-Roegen Energy and Economic Myths

ON ENERGY AND TIME - THE REALLY BIG PICTURE

We live on a planet of entropy, though its process it much too slow for us to notice. The first law of thermodynamics states that energy can not be created nor destroyed, only changed. The second law (the entropy law) states that low entropy (high potential) energy gradually but inexorably gets changed and degraded to high entropy (low potential) waste - each transformation results in a % of the original energy being lost as heat. Entropy can be slowed by leaving the low entropy sources alone, harnessing them more efficiently, or using their services more efficiently. Entropy can be hastened by opening the energy service spigot wider and wider, and using energy with little attention to how much is wasted. Unnoticed by everyone involved (except me, because Im writing this), my morning drive to Starbucks today took what was 1 gallon of high quality oil from beneath the sand in Saudi Arabia, and translated it to: a tiny amount of work for a great many people, a 30 minute joyous freedom-ride at 60 mph on a beautiful day, an unneccesary but pleasant jolt of hot caffeine, and about 115,000 BTUs dissipated into the earths atmosphere as heat, never to be used again. (I could have, were my priorities different, chosen to raise the temperature of 115,000 pounds of water by 1 degree Celsius - ahhh freedom.)

In this sense, energy is time itself, for once ALL usable energy is gone, and our sun reaches heat death, physically speaking time itself will cease to exist - for what is time other than a way to measure the process of entropy?(7) Amazingly, each American born today can be expected to live 77+/- years, and extrapolating the current roughly 60 barrel of oil equivalent per year use by the average American, use over 4,600 barrels of oil equivalent of energy during their lifetimes. (Note:

at 1 trillion barrels of global URR (ultimate recoverable reserves), that works out to 130 barrels per person for all time, and thats NOT including the impact of net energy). Looks like the 4,470+ will have to come from something other than oil, or we'll have to cut down on lifespan, or energy use per year, or both.

What if a magic machine that could allow each of us as individuals to allocate between energy and time for our own lives? How many people would choose to live to be 154 years old (77*2) but only use 30 boe per year (60/2)? My bet is quite a few. Take that a step further. How many would be willing to live to be 770 years old but only use 6 barrels of oil equivalent per year? Still some, but 770 years might get boring - thats a heck of a lot of Gilligans Island reruns - also 6 barrels per year isnt too many. How many would choose to live to be 7700 years old while using 6/10s a barrel per year of energy? Probably far fewer, (except for the vampires..;) The point being, not only is there a continuum between energy and time, but also of quality of life! People will and should conserve, but will they and should they beyond the point where there lives are improved. In this sense, I visualize a triad between energy, time, and quality, each having minimum values, beyond which steps towards one of the 3 are offset/substituted by one of the other two - we can increase in quality by decreasing our return on energy or time - we can increase our return on energy, by reducing our return on time, or quality, or some such concept.

CONCLUSIONS

Net energy is a physical measurement but can be meaningfully influenced by cultural valuations of other inputs (e.g. time). To me, net energy is most important in the following 2 senses: 1) given that we are beginning to acknowledge that the market does not provide perfect information, using net energy analysis to compare mitigation/adaptation strategies for the coming era of oil depletion is like looking 2 cars ahead in a snowstorm (the market is fixated on just the car taillights ahead). In this way one gets a truer sense of whats really happening up ahead because decisions are based on (at least partially) physical principles. Second, society continues to grow on a certain summation of energy density/quality and BTU total. As we exhaust the low hanging energy fruits, not only in oil, but in hydroelectric, coal, and other sources, to find the remaining, lower quality/density sources, more energy will have to be used. This energy doesn't come from the sky, but will be subtracted from the also declining amount of oil, natural gas, and electricity produced annually. Therefore the combination of these new energy technologies with end-use consumer efficiency improvements will have to overcome depletion and the increased energy requirement needed for lower EROI sources in order to maintain economic growth. Its really quite simple.

Ironically, net energy principles only purely work when time is not a factor. Given unlimited mitigation time, policymakers can use net energy analysis to determine the best use for our remaining high energy gain assets. But if fuel shortages develop, fixed infrastructure on the current declining energy return technologies may deliver more of an energy service payload to society than a new investment and scaling up of new technologies due to time lags.

The market is expensive in it's use of energy, not the least of reasons is that it incentivizes us to repeat iterations making money as often and quickly as possible. Getting things done quicker is much more important than getting them done using less energy. The market mechanism can coexist with oil depletion, but rules will eventually have to be created that coordinate our expected energy profit with our "E" (actual energy used), limit energy waste, choose what E brings the most meaningful and consistent human utility, and perhaps reduce our EROTI- energy return on time, thereby boosting the return on energy, or whatever the limiting factor is to human systems. A return to slower ways may not only provide us with more energy, but make us happier at the same time. How to get there?

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Next Up **"On The Origins of Exponential Growth, Part I"**

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