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Managing the Peak Fossil Fuel Transition: EROI and EIRR

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Tags: eroi, solar pv, wind [list all tags]

This is a guest post by Tom Konrad, Ph.D. This article was first published on his Clean Energy Wonk blog.

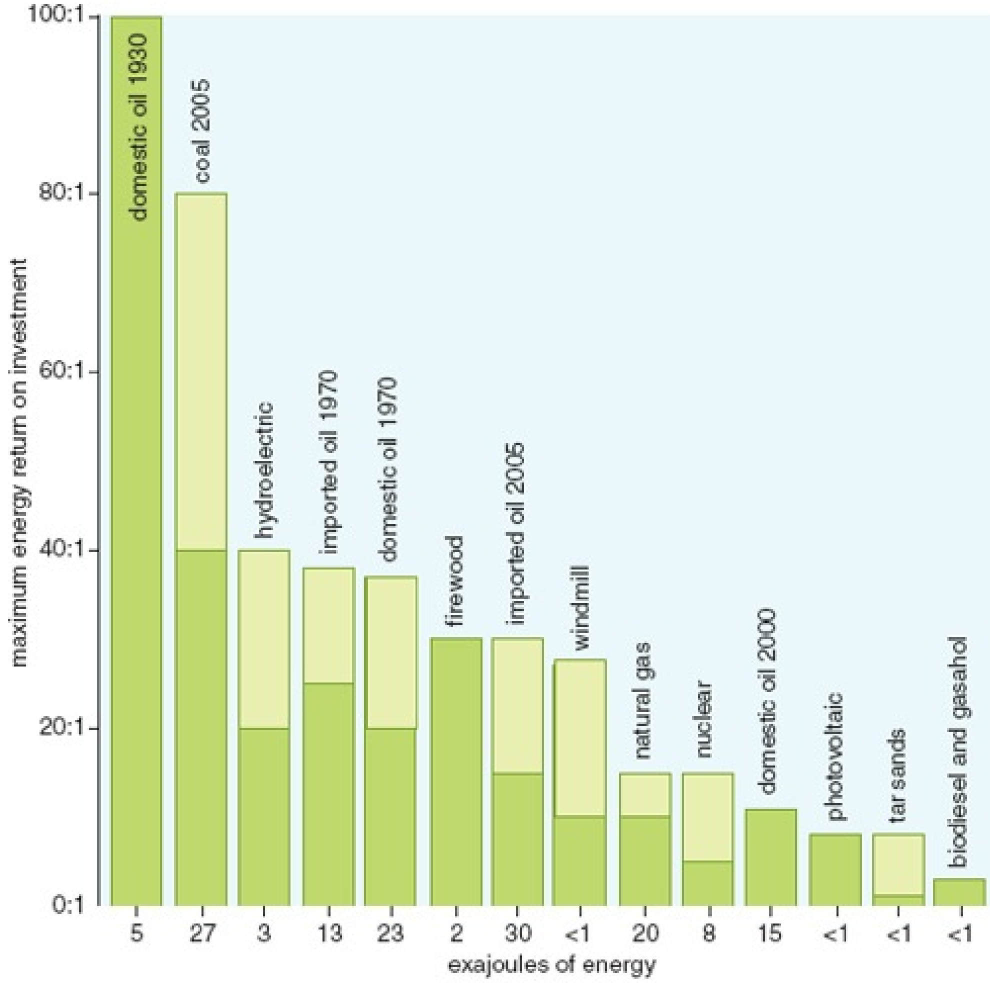
Current renewable energy technologies must be adopted in conjunction with aggressive Smart Growth and Efficiency if we hope to continue our current standard of living and complex society with diminished reliance on fossil fuels. These strategies have the additional advantage that they can work without large technological breakthroughs.

In this post I will talk about a topic which is likely familiar: Energy Return on Investment or EROI. I will also talk about Energy Internal Rate of Return (EIRR), a measure which is similar to EROI, but reflects how quickly society gets its energy return back from its energy investment.

Energy Return on Investment

Energy keeps our economy running. Energy is also what we use to obtain more energy. The more energy we use to obtain more energy, the less we have for the rest of the economy.

The concept of Energy Return on Investment (EROI), alternatively called Energy Return on Energy Invested (EROEI) has been widely used to quantify this concept. The following chart, from a SciAm paper, shows the EROI of various sources of energy, with the tan section of the bar representing the range of EROIs depending on the source and the technology used. I've seen many other estimates of EROI, and this one seems to be on the optimistic (high EROI) end for most renewable energy sources.



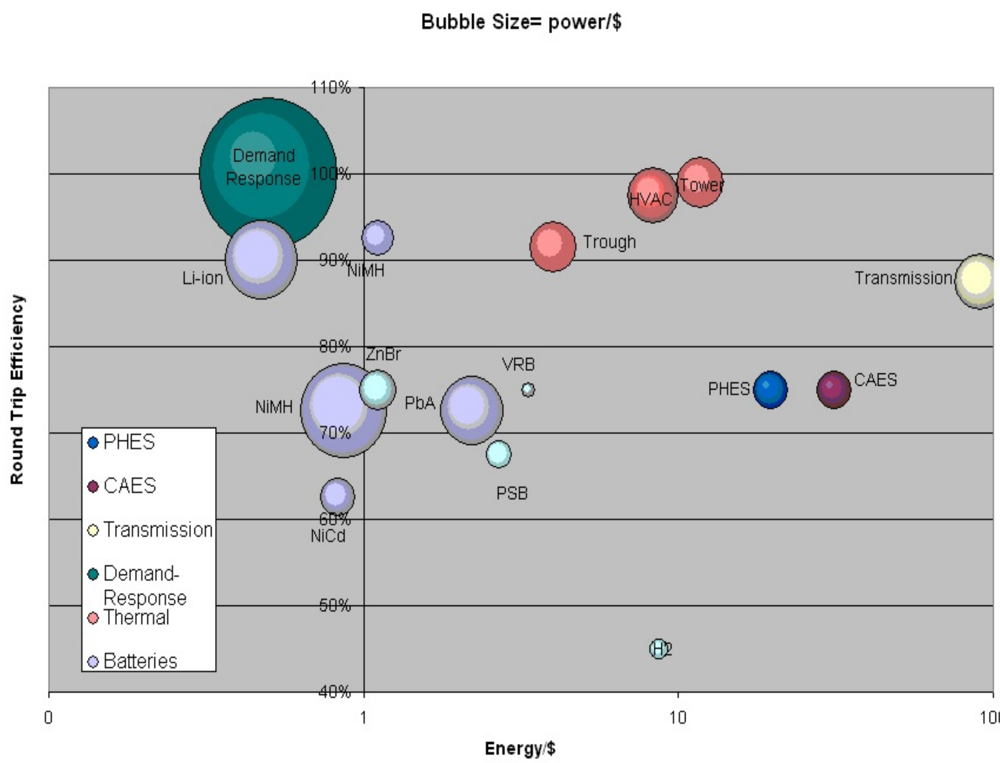
The general trend is clear: the energy of the future will have lower EROI than the energy of the past. Low carbon fuels such as natural gas, nuclear, photovoltaics, wind, and biofuels have low EROI compared to high-carbon fuels such as coal and (formerly) oil.

The graph also clearly shows the decline in the EROI over time for oil. Other fossil fuels, such as coal and natural gas, also will have declining EROI over time. This happens because we always exploit the easiest resources first. The biggest coal deposits that are nearest to the surface and nearest to customers will be the first ones we mine. When those are depleted, we move on to the less easy to exploit deposits. The decline will not be linear, and new technology can also bring temporary improvements in EROI, but new technology cannot change the fact that we've already exploited all the easiest to get deposits, and new sources and technologies for extracting fossil fuels often fail to live up to the hype.

While there is room for improvement in renewable energy technologies, the fact remains that fossil fuels allow us to exploit the energy of millions of years of stored sunlight at once. All renewable energy (solar, wind, biomass, geothermal) involves extracting a current energy flux (sunlight, wind, plant growth, or heat from the earth) as it arrives. In essence, fossil fuels are all biofuels, but biofuels from plants that grew and harvested sunlight over millions of years. I don't think that technological improvements can make up for the inherent EROI advantage of the many-millions-to-one time compression conveys to fossil fuels.

Hence, going forward, we are going to have to power our society with a combination of renewable energy and fossil fuels that have EROI no better than the approximately 30:1 potentially available from firewood and wind. Since neither of these two fuels can come close to powering our entire society (firewood because of limited supply, and wind because of its inherent variability.) Also, storable fuels such as natural gas, oil, and biofuels all have either declining EROI below 20 or extremely low EROI to begin with (biofuels). Energy storage is needed to match electricity supply with variable demand, and to power transportation.

Neither hydrogen nor batteries will replace the current storable fuels without a further penalty to EROI. Whenever you store electricity, a certain percentage of the energy will be lost. The percent that remains is called the round-trip efficiency of the technology, shown on the vertical axis of the graph below, taken from my earlier comparison of electricity storage technologies. (Click to enlarge.)



Round trip efficiency (RTE) for energy storage technologies is equivalent to EROI for fuels: it is the ratio of the energy you put in to the energy you get out. You can see from the chart, most battery technologies cluster around a 75% RTE. Hence, if you store electricity from an EROI 20 source in a battery to drive your electric vehicle, the electricity that actually comes out of the battery will only have an EROI of 20 times the RTE of the battery, or 15. Furthermore, since batteries decay over time, some of the energy used to create the battery should also be included in the EROI calculation, leading to an overall EROI lower than 15.

The round trip efficiency of hydrogen, when made with electrolyzers and used in a fuel cell, is below 50%, meaning that, barring huge technological breakthroughs, any hoped-for hydrogen economy would have to run with an EROI from energy sources less than half of those shown.

Taking all of this together, I think it's reasonable to assume that any future sustainable economy will run on energy sources with a combined EROI of less than 15, quite possibly much less.

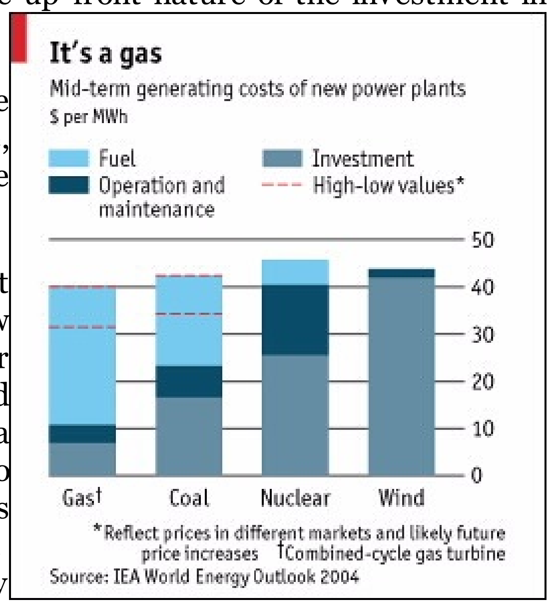
It's Worse than That: The Renewables Hump

All investors know that it matters not just how much money you get back for your investment, but how soon. A 2x return in a couple of months is something to brag about, a 2x return over 30 years is a low-yield bond investment, and probably hasn't even kept up with inflation.

The same is true for EROI, and means that users of EROI who are trying to compare future sources of energy with historic ones are probably taking an overly-optimistic view. For fossil fuels, the time we have to wait between when we invest the energy and when we get the energy back in a form useful to society is fairly short. For instance, most of the energy that goes into mining coal comes in the digging process, perhaps removing a mountaintop and dumping the fill, followed by the actual digging of the coal and shipping it to a coal plant. Massey Energy's 2008 Annual Report [pdf] states that "In 2008... we were able to open 19 new mines, and ten new sections at existing underground mines." This hectic rate of expansion leads me to believe that the time to open a new mine or mine section is at most 2 years, and the energy cycle will be even quicker at existing mines, when the full cycle between when the coal is mined and when it is burnt to produce electricity requires only the mining itself, transport to a coal plant, and perhaps a short period of storage at the plant. Most coal plants only keep a week or two supply of coal on hand.

In contrast, Nuclear and Renewable energy (with the exception of biofuels and biomass) present an entirely different picture. A wind farm can take less than a year to construct, it will take the full farm life of 20 years to produce the 10 to 30 EROI shown in the graph. Solar Photovoltaic's apparent EROI of around 9 looks worse when you consider that a solar panel has a 30 year lifetime. Only a little of the energy in for Nuclear power comes in the form of Nuclear fuel over the life of the plant: most is embodied in the plant itself.

Jeff Vail has been exploring this concept on his blog and the Oil Drum. He refers to the problem of the front-loading of energy investment for renewable energy as the Renewables Hump. He's also much more pessimistic than the above chart about the actual EROI of most renewables, and found this chart from The Economist which illustrates the up-front nature of the investment in Nuclear and Wind:



In terms of EROI timing, those technologies for which the cost of generation includes more fuel have an advantage, because the energy used to produce the fuel does not have to be expended when the plant is built.

In a steady state of technological mix, EROI is the most important number, because you will always be making new investments in energy as old investments outlive their useful lives and are decommissioned. However, in a period of transition, such as the one we are entering, we need a quick return on our energy investments in order to maintain our society. Put another way, Jeff Vail's "Renewables Hump" is analogous to a cash-flow problem. We have to have energy to invest it; we can't simply charge it to our energy credit card and repay it later. That means, if we're going to keep the non-energy economy going while we make the transition, we can't put too much energy today into the long-lived energy investments we'll use tomorrow.

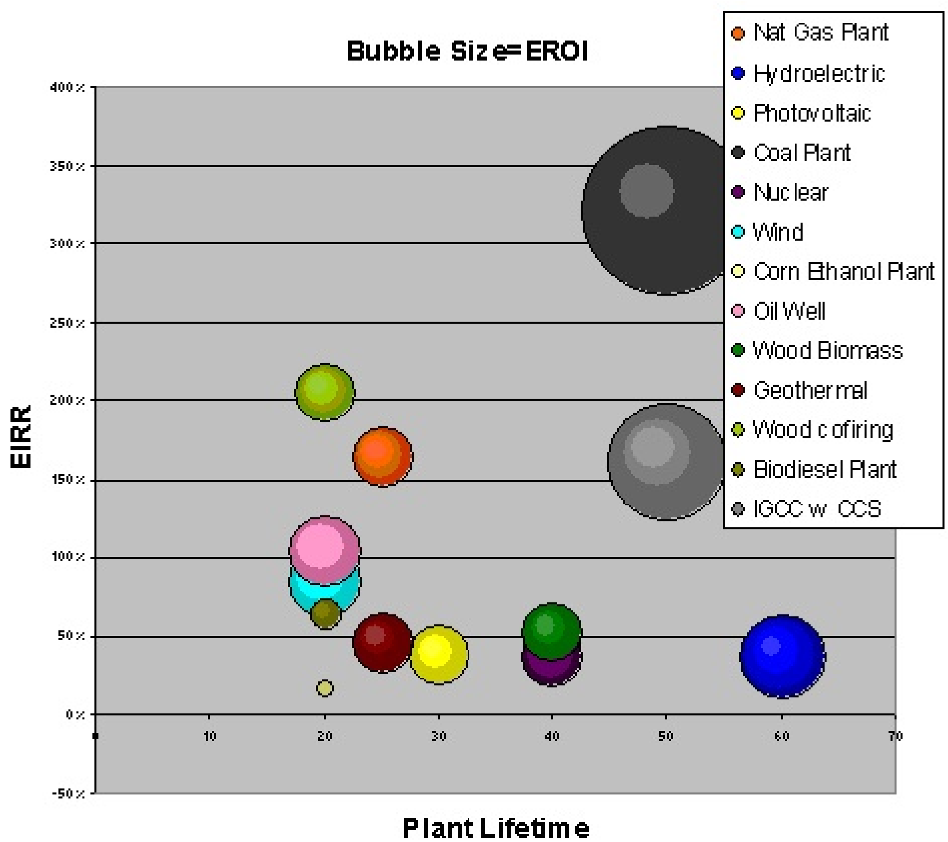
To give a clearer picture of how timing of energy flows interacts with EROI, I will borrow the concept of Internal Rate of Return (IRR) from finance. This concept is covered in any introductory finance course, and is specifically designed to be used to provide a single value which can be used to compare two different investments with radically different cash flow timing by assigning each a rate of return which could produce those cash flows if the money invested were compounded continuously.

Except in special circumstances involving complex or radically different size cash flows, an investor will prefer an investment with a higher IRR.

Energy Internal Rate of Return (EIRR)

I first suggested that IRR be adapted to EROI analysis by substituting energy flows for investment flows in early 2007. I called the concept [Energy Internal Rate of Return, or EIRR](). Since no one else has picked up the concept in the meantime, I've decided to do some of the basic analysis myself.

To convert an EROI into an EIRR, we need to know the lifetime of the installation, and what percentage of the energy cost is fuel compared to the percentage of the energy embodied in the plant. The following chart shows my preliminary calculations for EIRR, along with the plant lifetimes I used, and the EROI shows as the size of each bubble.



The most valuable energy resources are those with large bubbles (High EROI) at the top of the chart (High EIRR.) Because of the low EIRR of Photovoltaic, Nuclear, and Hydropower, emphasizing these technologies in the early stage of the transition away from fossil fuels is much more likely to lead to a Renewables Hump scenario in which we don't have enough surplus energy to both make the transition without massive disruption to the rest of the economy.

How to Avoid a "Renewables Hump"

Note that the three fossil fuels (oil, gas, and coal) all have high EIRRs. As we transition to lower carbon fuels, we will want to keep as many high EIRR fuels in our portfolio as possible.

The chart shows two renewables with EIRRs comparable to those of fossil fuels: Wood cofiring, and Wind. Wood cofiring, or modifying existing coal plants to burn up to 10% wood chips instead of coal was found to be one of the most economic ways of producing clean energy in the California RETI study. The scope for incorporating biomass cofiring is fairly limited, however, since it requires an existing coal plant (not all of which are suitable) as well as a local supply of wood chips. Some coal plants may also be converted entirely to wood, but only in regions with plentiful supplies of wood and for relatively small plants. The EIRR for this should fall somewhere between Wood cofiring and Wood Biomass, which is intended to represent the cost of new wood to electricity plants.

Natural Gas

To avoid a Renewables Hump, we will need to emphasize high-EIRR technologies during the transition period. If domestic natural gas turns out to be as abundant as the industry claims (there are serious doubts about shale gas abundance,) then natural gas is an ideal transition fuel. The high EIRR of natural gas fired generation arises mostly because, as shown in the chart "it's a gas" most of the cost (and, I assume energy investment) in natural gas generation is in the form of fuel. Natural gas generation also has the advantage of being dispatchable with generally quick ramp-up times. This makes it a natural complement to the variability of solar and wind.

However, I think it is unlikely that we'll have enough domestic natural gas to both (1) rely much more heavily on it in electricity generation and (2) convert much of our transportation fleet to natural gas, as suggested by T Boone Pickens. We're going to need more high-EIRR technologies to manage the transition. Fortunately, such technologies exist: the more efficient use of energy.

Energy Efficiency and Smart Growth

I have been unable to find studies of the EROI of various efficiency technologies. For instance, how much energy is embodied in insulation, and how does that compare to the energy saved? We can save transportation fuel with Smart Growth strategies such as living in more densely populated areas that are closer to where we work, and investing in mass transit infrastructure. The embodied energy of mass transit can be quite high in the case of light rail, or it can be very low in the case of better scheduling and incentives for ride sharing.

Many efficiency and smart growth technologies and methods are likely to have *much* higher EIRRs than fossil fuels. We can see this because, while the embodied energy has not been well studied, the financial returns have. Typical investments in energy efficiency in utility run DSM programs cost between $0.01 and $0.03 cents per kWh saved, much less than the cost of new fossil-fired generation. This implies a higher EIRR for energy efficiency, because part of the cost of any energy efficiency measure will be the cost of the embodied energy, while all of the savings are in the form of energy. This relationship implies that higher IRR technologies will generally have higher EIRRs as well.

Smart growth strategies also often show extremely high financial returns, because they reduce the need for expensive cars, roads, parking, and even accidents [pdf.]

Conclusion: Brain or Brawn

The Renewables Hump des not have to be the massive problem it seems when we only look at supply-side energy technologies. By looking at demand side solutions, such as energy efficiency, conservation, smart growth, and transit solutions, we need not run into a situation where the energy we have to invest in transitioning from finite and dirty fossil fuels to limitless and clean renewable energy overwhelms our current supplies.

Efficiency and Smart Growth are "Brain" technologies, as opposed to the "Brawn" of traditional and new energy sources. As such, their application requires long-term planning and thought. Cheap energy has led to a culture where we prefer to solve problems by simply applying more brawn. As our fossil fuel brawn fades away, we will have to rely on our brains once again if we hope to maintain anything like our current level of economic activity.