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Ten Fundamental Principles of Net Energy

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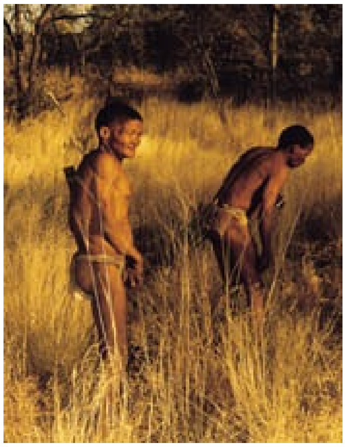
This is a guest post from Cutler Cleveland. Theoildrum.com previously highlighted Dr. Clevelands work on the Energy Return from Wind. Todays post is Professor Clevelands latest installment on net energy analysis at the Encyclopedia of Earth, which I have reformatted to theoildrum. The Encyclopedia of Earth, where Prof. Cleveland is an editor/director, has made amazing progress in its short history attempting to become an academic/content based web clearinghouse for information on earth and our environment. I encourage everyone to follow some of the hyperlinks in the below story and peruse that site.

Outside of taxes and profits, we are a society used to thinking in gross terms. But the net is what we get to use. Net energy is how much energy is left for productive purposes after the energy needed to find, concentrate and deliver its energy services are subtracted. Net energy analysis, (and its subset EROI) get alot of airtime in peak oil discussions. If the world is running on a certain total energy surplus, what are the implications for a decline in this surplus? Will the market, via dollars, anticipate or obviate a future constrained by biophysical limits? There seems to be much disagreement as to how best to use EROI and net energy principles, if at all, in tackling what we perceive on the horizon as a looming energy crisis. In this piece, Dr. Cleveland gives and overview of the central tenets of net energy analysis, in a broader perspective that we are used to on this site.



!Kung Hunter Gatherers- Figuring out net energy?

Introduction

Energy return on investment (EROI) is the ratio of the energy extracted or delivered by a process to the energy used directly and indirectly in that process. A common related term is energy surplus, which is the gross amount of energy extracted or delivered, minus the energy used directly and indirectly in that process. EROI is a dimensionless number, while energy surplus refers to an actual physical quantity of energy. Suppose an energy delivery system delivers 10 joules of energy, but in the process consumes 2 joules. The EROI for that process is 5 (10 divided by 2), while the energy surplus delivered is 8 joules (10 minus 2).

EROI is a tool of net energy analysis, a methodology that seeks to compare the amount of energy delivered to society by a technology to the total energy required to find, extract, process, deliver, and otherwise upgrade that energy to a socially useful form. Net energy analysis was developed in response to the emergence of energy as an important economic, technological and geopolitical force following the energy price increases of 1973-74 and 1980-81. Interest in net energy analysis was rekindled in recent years following another round of energy price increases, growing concern about energy's role in climate change, and the debate surrounding the remaining lifetime of conventional fossil fuels, especially crude oil.

The principles

1. Net energy and energy surplus are important driving forces in ecology and economic systems

The efficiency and effectiveness of energy capture is a central organizing principle in ecology. Living organisms must capture energy and allocate it among a number of life-sustaining tasks (growth, reproduction, energy storage, defense, competition). A larger surplus produced by a system of energy capture compared to competing strategies gives an organism a competitive advantage. Ecologists have used the principle of net energy to explain a wide range of phenomena, including habitat switching, long distance migration by birds, vertical migration by marine organisms, optimal foraging strategy, the pattern of the distribution and abundance of species, reproductive behavior in bats, and the effects of human disturbance on organisms.

Biologists such as Alred Lotka and Howard Odum elevated the concept to the driving force behind natural selection itself, where, in the struggle for existence, the advantage goes to those organisms whose energy-capturing devices are more effective in directing available energies into channels favorable to the preservation of the species.

Scholars from a number of disciplines have applied the same concept of net energy to social systems, with widely varying assumptions about the extent to which net energy influences the trajectory of the evolution of culture. The analogy to natural systems is straightforward: societies with access to energy sources with a higher EROI and a large net energy surplus have an economic and military advantage over societies that use lower quality energy sources. A low EROI means that more of a society’s productive resources must be devoted to energy delivery, and thus cannot be used to produce non-energy goods and services, support a powerful military, expand the arts, or be consumed as leisure time.

Net energy has been used to explain major energy transitions, including the industrial revolution and the emergence of the affluent society, the rise and fall of great civilizations, the pattern of resource depletion, and the impact of technological change on energy technologies. Net energy has been used as a methodological tool to assess and compare energy systems, as a tool to assess the climate impact of energy technologies, and it plays a central role in the longstanding debate on the viability of alternative energy technologies such as ethanol.

2. The size and rate of delivery of surplus energy is just as important as EROI

The net amount of energy delivered from the energy sector to the non-energy sectors is the energy available to generate non-energy goods and services. The size of that surplus sets broad but distinct limits on human economic aspirations. Falling water, for example, can deliver a large EROI in a specific location, but the total energy surplus available to a society from falling water is limited by the relatively sparse spatial distribution of the resource. The amount of energy surplus potentially available from diffuse energy sources such as solar and wind power is just as important as their EROI.

Contrary to popular belief, agriculture did not supplant hunting and gathering as the major food production technology because it had a higher EROI. Indeed, hunting and gathering often produced a very high EROI in specific locations and around specific resources. For example, the harvesting of energy-dense biomass in coastal whaling had an EROI in the neighborhood of 2000:1. Some hunting and gathering societies developed sophisticated social and civil institutions, and often consumed their energy surplus in the form of leisure time. But hunting and gathering ultimately is limited by the distribution of edible net primary production in the biosphere, which limits population densities to about one person per square < a href="http://www.eoearth.org/article/Meter">kilometer.

The advantage of agriculture derives from the large net energy surplus delivered per unit land area and per person compared to hunting and gathering. Agriculture thus erased the energetic limits to carrying capacity inherent in hunting and gathering, and released human labor and other productive resources from the farm. The latter was a necessary condition for the industrialization of society.

3. The unprecedented expansion of the human population, the global economy, and per capita living standards of the last 200 years was powered by high EROI, high energy surplus fossil fuels.

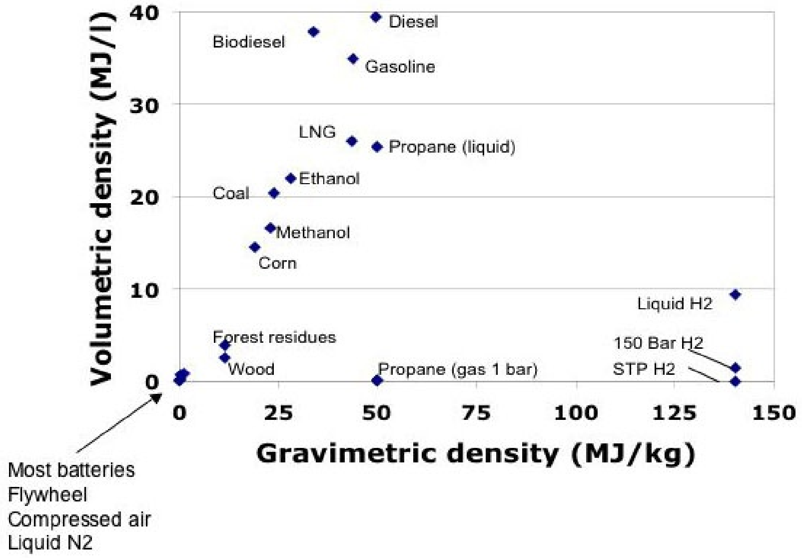
The penultimate position of fossil fuels in the energy hierarchy stems from the fact that they have a high EROI and a very large energy surplus. The largest oil and gas fields, which were found early in the exploration process due to their sheer physical size, delivered energy surpluses that dwarfed any previous source (and any source developed since then). That surplus, in combination with other attributes, is what makes conventional fossil fuels unique. The long run challenge society faces is to replace the current system with a combination of alternatives with similar attributes and a much lower carbon intensity.

4. The principal economic impact of a shift to a lower EROI energy system is the increased opportunity cost of energy delivery.

A shift to a lower EROI energy system means that more of society's productive resources are devoted--directly and indirectly-- to delivering the same amount of energy. That energy thus cannot be used for other purposes, notably consumption goods. Energy used to make a drilling rig or wind turbine cannot be used to manufacture iPods or provide medical care.

5. Energy quality matters

Net energy is only one attribute of an energy system that determines it usefulness to society. The usefulness of an energy system is determined by a complex combination of physical, technical, economic, and social attributes. These include gravimetric and volumetric energy density, power density, emissions, cost and efficiency of conversion, financial risk, amenability to storage, risk to human health, and ease of transport. These attributes combine to determine energy quality: differences in the ability of a unit of a fuel to perform useful services for people. No single metric of an energy system captures all such attributes, including EROI. It stands to reason, therefore, that a comprehensive and balanced comparison of energy technologies should employ a range of metrics, with their strengths and weaknesses duly noted.



Energy content per unit mass and per unit volume for various sources (click to Enlarge)

Since all forms of energy can be completely converted to heat, heat units (Btus, joules, calories, kilowatt-hours) provide an easy way to aggregate different forms of energy. For example, the world uses about 450x1015 Btu, or 450 "quads" of energy each year. That quantity is the aggregation of dozens of different energy types added together by multiplying their mass or volume used times their heat content per unit mass or volume. But this approach implicitly assumes that "all Btus are equal," i.e., that people value a heat unit of electricity the same as a heat unit of coal. Of course, this is not the case. Electricity performs important tasks that coal cannot, or it performs them more effectively. People are willing to pay 15 times more for a heat unit of electricity (in the U.S.) because of these differences. Accounting for differences in energy quality can dramatically alter the results of net energy analyses.

6. Market imperfections that distort prices and cost also affect EROI

Dollar-based assessments of energy systems are distorted by market imperfections such as externalities, subsidies, and government policies. The result is that the full social cost of energy is unaccounted for. However, EROI is plagued by many of the same problems. For example, there is no established methodology to incorporate the ecological and human health impacts of energy production and use in the calculation of EROI, so it too overstates benefits to society. In fact, economic analysis has better developed tools to estimate and aggregate external costs than energy analysis.

The calculation of indirect costs in energy analysis (e.g., the energy used to manufacture a wind turbine) often is based on economic data. Subsidies and other government policies affect decisions made in the market, and thus affect the economic data often used as inputs to energy analysis, including the pattern of capital investment. A good example of this was government regulation of the natural gas industry in the U.S. in the 1970s. Deep, new, and presumably lower EROI natural gas was assigned a higher price than shallow, old, and presumably higher EROI gas in an attempt to stimulate overall exploration. Any change in the overall EROI for gas extraction caused by this policy had little to do with “resource depletion” per se.

7. The methodologies to perform net energy analysis are well established

Conventional wisdom in the blogsphere and other Internet communities is that there are no guidelines for performing net energy analysis. In fact, there is a rich, well-established body of literature on the subject, most of which was developed in the first wave of energy research in the 1970s and 1980s. This body of work includes not only methodological detail, but also discussions about how to deal with intractable problems such as joint costs and outputs, the energy cost of human labor, choosing appropriate system boundaries, among many others. The record also has a rich history of debate about the virtues of net energy analysis, particularly in regards to what it adds, if anything, to a discussion that already includes a thorough economic assessment. The current discussion surrounding net energy analysis would be significantly enhanced if participants were better informed by previous work.

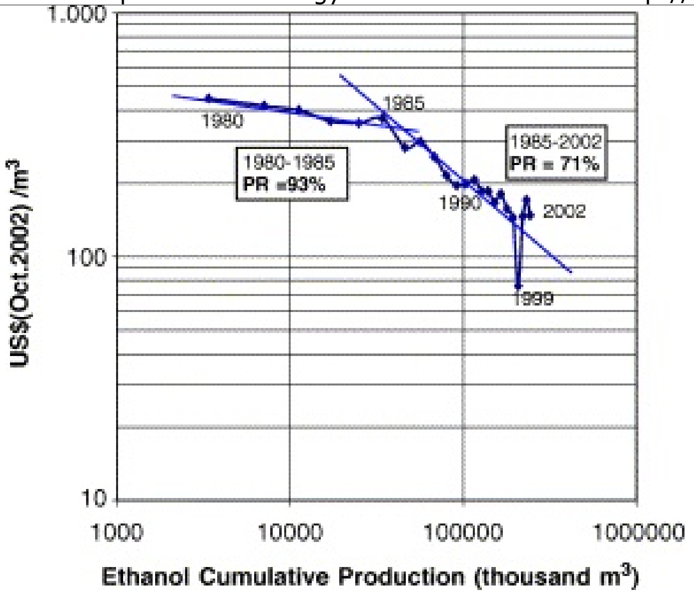
8. The relation between “peak oil” and the EROI for world oil production is unknown

This statement is true for two reasons. The first and most obvious reason is that we do not know when world oil production will peak, and won’t know definitively until sometime afterwards. Second, and more importantly, there is no comprehensive and reliable assessment of the historic EROI for world oil production. There is a distinct lack of reliable public data on the direct and indirect costs associated with oil production in many regions of the world.

The lower 48 U.S. is the only region for which we can compare the trends in EROI and oil production. There we see a remarkable convergence: crude oil production peaks in 1970 and then declines, and the EROI for that production peaks at about the same time. The timing of both peaks is consistent with a change in the underlying cost structure of the resource, when the cost-increasing effects of depletion began to outweigh the cost-decreasing effects of technological change. If such as connection holds at the global level, then the timing and impact of “peak oil” takes on added significance.

9. Technological change affects EROI just as it affects price and cost

There is a widely held assumption that the EROI for a nonrenewable energy resource such as crude oil or a renewable resource such as wind inexorably decline once the physical quality of the resource base begins to decline (e.g., smaller and deeper fields, or less windy sites). This is not necessarily the case. Technological change that lowers the dollar cost of extraction can also lower the energy cost of extraction. For example, developing the ability to drill multiple and directional wells from a single platform lowered the dollar cost per well, and it may well have lowered the indirect energy embodied in the materials required to extract oil. The well-documented technical improvements that have lowered the dollar cost of emerging technologies such as wind and solar undoubtedly exert at least some downward pressure on energy costs as well.



The decline in cost for ethanol fuel produced from sugarcane in Brazil (click to Enlarge)

Technological change exogenous to the energy industry also affects the EROI. For example, the development of more efficient combustion engines would, ceteris paribus, improve the EROI for oil extraction that relies on such engines to lift oil to the surface. Similarly, a decrease in the quantity of energy required to produce a kilogram of steel will, ceteris paribus, improve the EROI by reducing the energy embodied in oil field equipment.

10. Alternatives to the dominant energy and power systems show a wide range in EROI

Most alternatives to conventional liquid fuels have very low or unknown EROIs. The EROI for ethanol derived from corn grown in the U.S. is about 1.5:1, well below that for conventional motor gasoline. Ethanol from sugarcane grown in Brazil apparently has a higher EROI, perhaps as high as 8:1, due to higher yields of sugarcane compared to corn, the use of bagasse as an energy input, and significant cost reductions in ethanol production technology. Shale oil and coal liquefaction have low EROIs and high carbon intensities, although little work has been done in this area in more than 20 years. The Alberta oil sands remain an enigma from a net energy perspective. Anecdotal evidence suggests an EROI of 3:1, but these reports lack veracity. Certainly oil sands will have a lower EROI than conventional crude oil due to the more diffuse nature of the resource base and associated increase in direct and indirect processing energy costs.

On the power generation side, coal, and hydropower have the highest EROI among conventional power systems, although the latter has very limited potential for further expansion in most regions of the world. Nuclear power appears to have a lower EROI, but there are very few credible studies that are thorough and unbiased. We do not know what the EROI will be from the new generation of nuclear reactors that would be built if demand for them returns. Wind has a very favorable EROI in the right conditions, while solar thermal and photovoltaic systems have lower EROIs compared to coal and hydropower. As outlined above, a key issue is the size of the surplus that can realistically be delivered by those renewable power technologies.

A final point for consideration:

Carbon may trump EROI. The growing concern that climate change may impose swift and large costs on society may drive the next major energy transition. It is plausible that carbon intensity, as opposed to net energy, may be the principal attribute of future energy systems that determines the timing and pace of their adoption. Society may choose to forgo the benefits of a larger energy surplus to reduce its exposure to climate-related risks.

Further reading

Original posting of the article at the Encyclopedia of Earth *here*

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