

Editorial

Synthesis to Special Issue on New Studies in EROI (Energy Return on Investment)

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Abstract: This paper is a synthesis of a series of twenty papers on the topic of EROI, or energy return on investment. EROI is simply the energy gained from an energy-obtaining effort divided by the energy used to get that energy. For example, one barrel of oil invested into getting oil out of the ground might return fifty, thirty, ten or one barrel, depending when and where the process is taking place. It is meant to be read in conjunction with the first paper in this special issue and also a number of the papers themselves. As such I try to summarize what general trends we might conclude from these varied and often highly technical papers. About half of the papers are reports on empirical analyses of various energy sources such as Norwegian or Gulf of Mexico oil, Pennsylvania gas and so on. About a quarter of the papers are methodological: how do we go about undertaking these analyses, what problems are there, what are the proper boundaries and so on. The final quarter are in a sense philosophical: since it appears that we will be living indefinitely in a world of decreasing EROIs, what are the economic, social and psychological implications? The rest of this paper summarizes the results of these studies.

Keywords: energy; EROI; economic; fuels; quality of fuels

There is, at least in my mind, a remarkable uniformity in the conclusions of essentially all of these papers, and also a very clear confirmation and continuation of the patterns derived in former EROI studies from the 1970s and 1980s but largely forgotten. The most general conclusions are that (1) traditional fossil fuels almost universally have a higher, often a much higher, EROI than most substitutes (especially when backup systems are included), (2) nevertheless, the EROI of essentially all

fossil fuels studied are declining, in many cases sharply, and (3) that the economic implications of these are enormous. I do not see within this suite of studies anything that implies a “business as usual” (*i.e.* growth) as the most likely scenario representing the future. More probably the “undulating plateau” of the past half-decade or so will continue followed by a gradual decline in the availability of our most important fuels. Even our most promising new technologies appear to represent at best minor, even trivial, replacements for our main fossil fuels at least within anything like the present investment and technological environment. Given that government and the public are fed a continual barrage of “solutions” for our energy problem (few if any with quantitative assessments) it is not surprising that there is little concern about, preparation for, or even discussion of preparations for what is likely to be a future of progressively lower net energy availability. Such a decline in net energy is almost guaranteed for the US (and much of the rest of the world) if and as conventional global oil production declines as expected, as a smaller proportion of that produced is available for export, as oil and natural gas becomes energetically, financially and environmentally more costly, as debt issues make our credit less secure, as our 104 nuclear power plants reach retirement age more or less simultaneously and as the population continues to increase. These papers collectively do not offer a clean technical solution to these issues, for depletion seems to be effectively trumping technical progress again and again.

Other main conclusions from this special issue include:

- (1) The energy return on investment for essentially all major fuels for the world (the sun driving natural processes excluded) are declining over time.
- (2) This pattern of declining EROI was found for US oil and gas (Guilford *et al.*), Norwegian oil and gas (Grandell *et al.*), Chinese oil (Yan *et al.*), California oil (Brandt), Gulf of Mexico oil and gas (Day and Moerschbaecher), Pennsylvania gas (Sell *et al.*) and Canadian gas (Freese).
- (3) The more rapidly a given fuel is exploited the more rapidly its EROI at that time declines (*i.e.* EROI for oil and gas declines more rapidly when exploitation intensity is high).
- (4) When assessments are included that include the dynamics of a ramping up a supply system the EROI is likely to become lower than what would otherwise be the case—in other words expansion itself has a large energy cost.
- (5) The EROI declines for the discovery of oil far more rapidly than for oil and gas together—in other words gas seems to subsidize oil (Guilford *et al.*).
- (6) Changes in EROI are reflected in the changing prices of fuels (King and Hall).
- (7) All estimates of EROI are likely to be overestimates because they do not include the energy costs of labor, of finance and other expenditures (Henshaw and King).
- (8) Previous criticisms of the utility of EROI because different studies gave different answers seem not to be especially valid, for the differences are due much less to different estimates of energy costs than to rather philosophical differences of what should or should not be included in costs and gains.
- (9) Different (and legitimate) questions about the boundaries of analysis or philosophies of analysis (Hall, Dale and Pimentel, Henshaw *et al.*) can be accommodated within the new EROI protocol put forth here by Murphy *et al.* The new EROI protocol offered here allows a means of allowing the use of different philosophies while providing a standard procedure that would allow comparison among studies.

- (10)EROI for the *finding* of oil and gas has declined much more precipitously than that for the *production* of oil and gas.
- (11)The only really important change since the earlier studies of the 1980s has not been any of the facts of EROI but rather the public perception of the importance of energy. This flourished during and just after the energy crises of the 1970s, then waned, and has now reemerged. The American public and its leadership are completely unprepared for the consequences.

There are many other unanswered problems to whatever new energy technologies may be coming our way: can the technical progress of photovoltaic systems be continued without using energy-intensive exotic materials, would there be enough copper and other materials, can backup systems be derived for massive wind power systems without bringing the EROI down to unmanageable levels? Can we have anything like our present level of affluence and civilization on fuels of modest EROI? And then there is the question of coal: this remains abundant in the US and several other areas of the world but its environmental problems are of course very severe. Because of the environmental concern about nuclear power and the decline in available oil or at least its growth the increased energy use in the US and other large countries has normally fallen by default to coal. This is likely to continue without some kind of coordinated plan.

Curiously the importance of EROI studies has escaped the notice of our major funding agencies and nearly all of the research reported on here was done without any governmental, or other, funding. We thank all those who believe so strongly in this issue that they were willing to undertake these studies “*pro bono*”. This special issue has not covered several other issues that are likely to be critical. One in particular is the issue of investments. As it stands the price of gasoline at the pump covers only the cost of extracting and refining the oil, it does not cover the cost of replacement, were that possible. Hence when the majority of the existing reservoirs are pumped dry will the public be willing to pay double the otherwise high cost of gasoline to pay for the investments into whatever alternative fuels are available? Some may already be doing that through the very high cost of electric vehicles. What if fleets of electric vehicles add large loads to already overburdened electric utility lines? Who pays for the upgrades?

All of these issues need to be dealt with in some kind of massive objective synthesis. Instead there are advocacy groups for and against each individual fuel with little understanding that arguing against one fuel almost certainly means encouraging another (as in the nuclear-coal issue above). “Green technologies” are not displacing fossil fuels, whose use continues to grow, but simply adding a little to the mix. Large energy companies are easy targets and they certainly do many foolish things. But basically they are doing no more than what citizens are asking for: provide more power for an energy-intensive life style. Even our largest oil companies that periodically make massive and alienating profits are just average with respect to corporate profits when measured over a decade, as they tend to have years with very poor returns as well. Pharmaceutical and soft drink companies have far higher profit rates. If you personally do not like the actions of oil companies that is fine, but I would suggest that you stop buying gasoline or using a bus before you cry out too much. Also there is little understanding that while one fuel or another does indeed tragically kill a dozen miners here or oil workers there (as in any huge industry), that collectively our energy-intensive industrial society has saved probably billions of lives and added decades to our life spans. This is through better nutrition,

more even experienced temperatures and the whole health-medical establishment, all of which are very energy-intensive.

Clearly a massive analysis is necessary to understand all of these questions. There has been little leadership from Washington, especially on the need for massive conservation, but rather cheerleading for technologies that offer little. Most obviously the large federal encouragement for corn-based ethanol has generated a vast bureaucracy that has provided little or no net fuel to the nation despite many scientific studies that indicated long ago that the net contribution of this fuel, even not accounting for the soil erosion, was quite marginal at best. Universities are probably the best vehicles for providing this assessment but funding for such analyses, or even to develop sufficiently well-trained man and woman power, make even this inexpensive and logical step rather unlikely in today's political climate. Given the connection between EROI and fuel price shown by King and Hall in this issue it seems that markets will continue to maintain fossil fuels as dominant fuels until their own EROIs, including backups and perhaps environmental issues, are in the same range, if that ever occurs. Despite all the rhetoric the proportional contribution of oil, gas and coal has not changed much at all since the 1970s. Even if some magic new technology is found, encouraged and the necessary investments are found it is likely to have a low EROI relative to traditional fuels. If it were to grow exponentially it could be a sink of net energy from society for some time, even decades (see Deng and Tyron [1], this issue, and Gutowski *et al.* [2]). There are no simple solutions to our energy dilemma and they need to be understood much better, especially with respect to economics. We try to do that in a new book [3] which examines how we might think quite different about economics from the perspective of energy and all of the issues identified here.

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Conflict of Interest

There are no conflicts of interest associated with this paper.

References and Notes

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