

ENERGY RETURN ON INVESTMENT

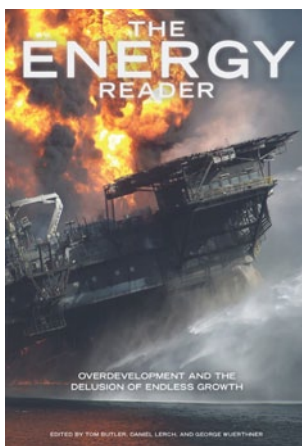
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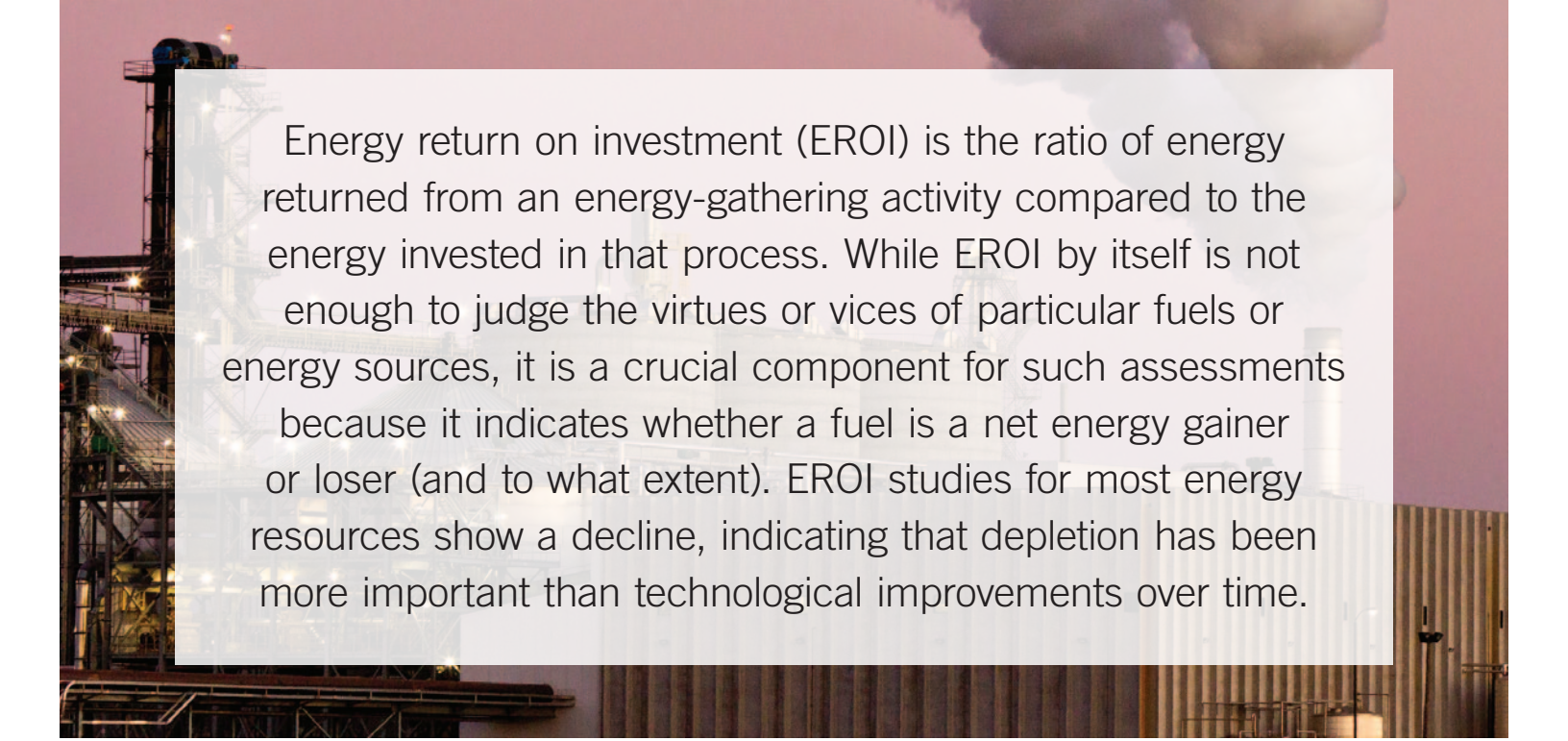
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This publication is an excerpted chapter from *The Energy Reader: Overdevelopment and the Delusion of Endless Growth*, Tom Butler, Daniel Lerch, and George Wuerthner, eds. (Healdsburg, CA: Watershed Media, 2012). *The Energy Reader* is copyright © 2012 by the Foundation for Deep Ecology, and published in collaboration with Watershed Media and Post Carbon Institute.

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Photo: Chuck Haney. *Ethanol plant, North Dakota.*



Energy return on investment (EROI) is the ratio of energy returned from an energy-gathering activity compared to the energy invested in that process. While EROI by itself is not enough to judge the virtues or vices of particular fuels or energy sources, it is a crucial component for such assessments because it indicates whether a fuel is a net energy gainer or loser (and to what extent). EROI studies for most energy resources show a decline, indicating that depletion has been more important than technological improvements over time.

Energy return on investment (EROI)¹, or sometimes “energy return on energy investment” (EROEI), is the ratio of energy returned from an energy-gathering activity compared to the energy invested in that process. (The word “investment” usually means energy investment, but sometimes net energy analysis also includes financial, environmental, and/or other kinds of investments.) The term EROI has been around since at least 1970, but it gained relatively little traction until the last five or ten years. Now there is an explosion of interest as peak oil and the general economic effects of increasingly constrained energy supplies are becoming obvious to investigators from many fields. Many observers feel that the financial crises we have been experiencing since 2008 are a direct effect of the end of oil production growth (of all liquid fuels if considered on an energy basis) and of the general decline in EROI for most energy sources.

While EROI by itself is not enough to judge the virtues or vices of particular fuels or energy sources, it is an extremely important component for such assessments. Most importantly, it can indicate if a fuel is a net energy gainer or loser—and to what extent. It also offers the possibility of looking into the future in a way that markets are unable to do: EROI advocates believe that, in time, market prices must approximately reflect comprehensive EROIs (at least if appropriate corrections for energy quality are made and

financial subsidies for energy and fuel production are removed).²

THE IMPORTANCE OF EROI

Many prominent earlier researchers and thinkers (including sociologists Leslie White and Fred Cottrell, ecologist Howard Odum, and economist Nicolas Georgescu Roegan) have emphasized the importance of net energy and energy surplus as a determinant of human culture. Farmers and other food producers must have an energy profit for there to be specialists, military campaigns, and cities, and substantially more for there to be art, culture, and other amenities. Net energy analysis is simply a way of examining how much energy is left over from an energy-gaining process after correcting for how much of that energy—or its equivalent from some other source—is required to generate a unit of the energy in question.

The importance of EROI is far more than simply whether it is positive or negative. Several of the participants in the current debate about corn-derived ethanol believe that corn-based ethanol has an EROI of less than 1:1, while others argue that ethanol from corn shows a clear energy surplus, with from 1.2 to 1.6 units of energy delivered for each unit invested. But this argument misses a very important issue. Think of a society dependent upon one resource: oil. If the EROI

for this oil was 1.1:1 then one could pump the oil out of the ground and look at it ... and that's it. It would be an energy loss to do anything else with it. If it were 1.2:1 you could refine it into diesel fuel, and at 1.3:1 you could distribute it to where you want to use it. If you actually want to run a truck with it, you must have an EROI ratio of at least 3:1 (at the wellhead) to build and maintain the truck, as well as the necessary roads and bridges (including depreciation). If additionally you wanted to put something in the truck and deliver it, that would require an EROI of, say, 5:1.³ Now say you wanted to include depreciation on the oil field worker, the refinery worker, the truck driver, and the farmer; you would need an EROI of 7:1 or 8:1. If their children were to be educated you would need perhaps 9:1 or 10:1, to have health care 12:1, to have arts in their lives maybe 14:1, and so on.

Obviously to have a modern civilization one needs not just surplus energy, but lots of it—and that requires either a high EROI or a massive source of moderate-EROI fuels. If these are not available, the remaining low-EROI energy will be prioritized for growing food and supporting families.

If the energy and hence economic pie is no longer getting larger—indeed, if because of geological constraints it can no longer get larger—how will we slice it? This may force some ugly debates back into the public vision. If EROI continues to decline then it will cut increasingly into discretionary spending (the engine for economic growth) and we will need to ask some very hard questions about how we should spend our money.

A problem with substitutes to fossil fuels is that, of the alternatives currently available, none appear to have all the desirable traits of fossil fuels, especially liquids. These include sufficient energy density, easy transportability, relatively low environmental impact per net unit delivered to society, relatively high EROI, and availability on a scale that society presently demands. Thus it would seem that the United States and the rest of the world are likely facing a decline in both the quantity and EROI of its principal fuels. How we adjust to this will be a critical determinant of our future.

THE ECONOMIC COST OF ENERGY

In real economies, energy is essential for any process to occur; that is, for the production and transport of goods and services (even for the production of financial services). In the United States, that necessary energy comes from many sources: from imported and domestic sources of oil (about 40 percent), coal and natural gas (about 20 percent each), from hydropower and nuclear (about 5 percent each), and from a little renewable energy (mostly as firewood but increasingly from wind and solar).

It is possible to examine the ratio of the cost of energy (from all sources, weighed by their importance) relative to the benefits of using it to generate wealth. In 2007, roughly 9 percent of gross domestic product (GDP) was spent to purchase the energy used by the U.S. economy to produce the goods and services that comprised the GDP. Over recent decades that ratio has varied between 5 and 14 percent. The abrupt rise and subsequent decline in the proportion of the GDP spent for energy was seen during the “oil shocks” of the 1970s, in mid-2008, and again in 2011. Each of these increases in the price of oil relative to GDP had large impacts on discretionary spending—that is, on the amount of income that people can spend on what they want versus what they need. An increase in energy cost from 5 to 10 or even 14 percent of GDP would come mainly out of the 25 percent or so of the economy that usually goes to discretionary spending. Thus changes in the amount we spend on energy (much of which goes overseas) have very large impacts on the U.S. economy since most discretionary spending is domestic. This is why each significant increase in the price of oil (and of energy generally) has been associated with an economic recession, and it suggests that declining EROI will take an increasing economic toll in the future.⁴

DETERMINING EROI

EROI is calculated from the following simple equation, although the devil is in the details:

$$\text{EROI} = \frac{\text{Energy returned to society}}{\text{Energy required to get that energy}}$$

The numerator and denominator are necessarily assessed in the same units so that the ratio derived is dimensionless (e.g., 30:1). This example means that a particular process yields 30 joules per investment of 1 joule (or kilocalorie per kilocalorie, or barrels per barrel). EROI is usually applied at the point that the energy resource leaves the extraction or production facility (i.e., at the mine-mouth, wellhead, farm gate, etc.); we denote this more explicitly as $EROI_{mm}$. Another approach uses a simple, standardized energy output divided by the direct energy (energy used at the production site) and indirect energy (energy used to manufacture the machinery and products used at the production site) consumed to generate that output. This results in a measurement of standard EROI, $EROI_{st}$.

Determining the energy content of the numerator of the EROI equation is usually straightforward: Simply multiply the quantity of energy produced by the energy content per unit. Determining the energy content of the denominator is usually more difficult. The energy used directly (i.e., on site) might include, for example, the energy used to rotate the drilling bit when drilling for oil, the energy used to excavate when mining for coal, or the energy used to operate the farm tractor when harvesting corn for ethanol. One also should include the energy used indirectly—that is, the energy used to manufacture the drilling bit, the excavation equipment, the tractor, and so on. Companies generally do not keep track of their energy expenditures in terms of joules, only in dollars. However, it is possible to convert dollars spent to energy spent using either the mean price of fuel for direct energy or by using “energy intensities” for dollars spent in different parts of the economy (such as were calculated by a University of Illinois research group in the 1970s⁵).

Of course, the EROI that is needed to profitably undertake some economic activity, such as driving a truck, is far more than just what is needed to get the fuel out of the ground. Starting with the EROI for an energy source from the point of production ($EROI_{mm}$), we can then consider what might be needed to refine that energy source and deliver it to its point of use; we could also include the (prorated) energy required to make

and maintain a vehicle and the roads it would drive on. This would give us EROI at the “point of use,” or $EROI_{pou}$: the ratio of energy available at a point of use to the energy required for acquiring and delivering that energy.

EROI OF OBTAINING ENERGY THROUGH TRADE

An economy without enough domestic fuels of the type it needs must import the fuels and pay for them with some kind of surplus economic activity. Thus the economy’s ability to purchase the required energy depends upon what it can generate to sell to the world, as well as upon the fuel required to grow or produce that material. The EROI for the imported fuel is the relation between the amount of fuel bought with a dollar relative to the amount of dollar profits gained by selling goods or services for export. The quantity of the goods or services that need to be exported to attain a barrel of oil depends upon the relative prices of the fuel versus the exported commodities.

In the 1980s, Boston University scholar Robert Kaufmann estimated the energy cost of generating a dollar’s worth of major U.S. exports (e.g., wheat, commercial jetliners), and also the chemical energy found in one dollar’s worth of imported oil.⁶ The concept was that the EROI for imported oil depended upon what proportion of an imported dollar’s worth of oil you needed to generate the money from overseas sales that you traded, in a net sense, for that oil. He concluded that, before the oil price increases of the 1970s, the EROI for imported oil was about 25:1 (very favorable for the United States); but this dropped to about 9:1 after the first oil price hike in 1973 and then to about 3:1 following the second oil price hike in 1979. The ratio returned to more favorable levels (from the perspective of the United States) from 1985 to about 2000 as the price of exported goods increased through inflation more rapidly than the price of oil. As oil prices increased again in the first decade of the twenty-first century—a period when the remaining conventional oil became concentrated in fewer and fewer countries, and future supply of conventional oil was of increasing concern—

that ratio declined again to roughly 10:1. Estimating the EROI of obtaining energy through trade may be very useful in predicting economic vulnerability for specific countries in the near future.

To some degree we have managed to continue purchasing foreign oil through debt, which gives us a temporarily higher EROI. Were we to pay off this debt in the future, and if those who got the dollars wished to turn them into real goods and services (which seems a reasonable assumption), then we would have to take some substantial part of our remaining energy reserves out of the ground and convert it into fish, rice, beef, cars, and other products that those people would be able to buy from us.

THE HISTORY OF EROI

EROI has precedents in the concept of “net energy analysis” used by Leslie White, Kenneth Boulding, and especially Howard Odum.⁷ Its origins were derived most explicitly in my 1970 doctoral dissertation on the energy costs and gains of migrating fish.⁸ The concept was developed in various papers throughout the 1980s, and although its use lagged during society’s “energy lull” from 1984 to 2005 it has since picked up significantly.⁹ Similar but less explicit and focused ideas can be found in the newer field of “life cycle analysis,” which is better developed in Europe than in the United States.

There have been questions about the degree to which we should use EROI versus more familiar measurements (e.g., financial return on financial investment in the oil business) to examine energy and other resource choices. In addition there have been criticisms that EROI has some severe flaws, such as that different studies give different answers to what appears to be the same question, that the boundaries of the analysis are controversial, that market solutions are always superior to “contrived” scientific studies, and that EROI too often is dependent upon monetary data for its results. Despite these real or imagined limitations, EROI is still a critical concept to understand when considering energy policy and the future prospects for modern civilization.

ENDNOTES

- 1 See Charles Hall, "Introduction to Special Issue on New Studies in EROI (Energy Return on Investment)," *Sustainability* 3, no. 10 (October 2011): 1773-1777. See also Charles Hall and Kent Klitgaard, *Energy and the wealth of nations: Understanding the Biophysical Economy*, (New York: Springer, 2011), and sources therein. The term "Energy returned on energy invested" (EROEI) is also commonly used.
- 2 C. King and C. Hall, "Relating Financial and Energy Return on Investment," *Sustainability* 3, no. 10 (October 2011): 1810-1832.
- 3 D.J. Murphy, C.A. Hall, M. Dale, C. Cleveland, "Order from Chaos: A Preliminary Protocol for Determining the EROI of Fuels," *Sustainability* 3, no. 10 (October 2011):1888-1907.
- 4 King and Hall, "Relating Financial and Energy Return."
- 5 C.W. Bullard, B. Hannon, R. Herendeen, *Energy Flow through the US Economy*, (Champaign, IL: University of Illinois Press, 1975); B. Hannon, *Analysis of the energy cost of economic activities: 1963-2000*, Energy Research Group Doc. No. 316, (Urbana: University of Illinois, 1981); R. Herendeen and C. Bullard, "The energy costs of goods and services," *Energy Policy* 3 (1975): 268; R. Costanza, "Embodied energy and economic valuation," *Science* 210 (1980): 1219-1224.
- 6 R. Kaufmann and C. Hall, "The energy return on investment of imported petroleum," in *Energy and Ecological Modeling*, ed. W.J. Mitsch, et al. (Amsterdam: Elsevier Scientific, 1981), 697-701. See also chapter 8 of C. Hall, C. Cleveland, and R. Kaufmann, *Energy and resource quality: the ecology of the economic process* (New York: Wiley, 1986).
- 7 H. T. Odum, "Energy, ecology and economics," *AMBIO* 2 (1973): 220-227.
- 8 C.A. Hall, "Migration and Metabolism in a Temperate Stream Ecosystem," *Ecology* 53 (1972): 585-604.
- 9 See R. Heinberg, *Searching for a Miracle: 'Net Energy' Limits & the Fate of Industrial Society*, (San Francisco: International Forum on Globalization, 2009), <http://www.postcarbon.org/report/44377-searching-for-a-miracle>.

ENERGY

Overdevelopment and the Delusion of Endless Growth

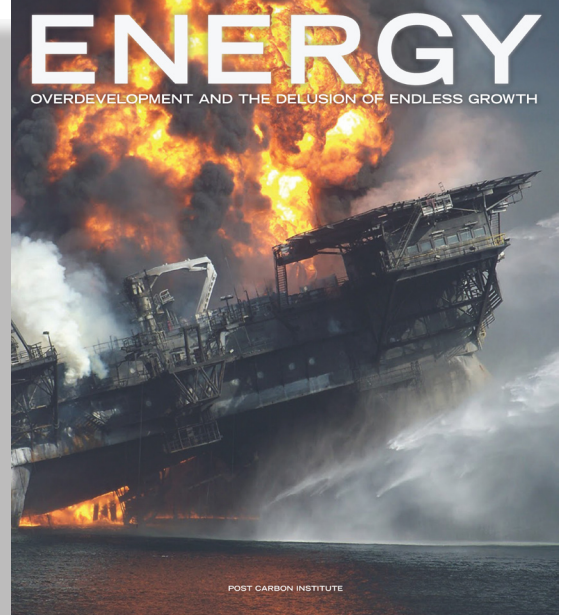
Edited by Tom Butler and George Wuerthner

We have reached a point of crisis with regard to energy... The essential problem is not just that we are tapping the wrong energy sources (though we are), or that we are wasteful and inefficient (though we are), but that we are overpowered, and we are overpowering nature.

— from the Introduction, by Richard Heinberg

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