An EROEI Primer

"For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."
- Richard Feynman

Numerous factors are considered when evaluating prospective energy production facilities. The outcome of a financial cost-benefit analysis is the key factor for most developers. Dependence on additional resources and environmental consequences are more relevant to those living proximate and downstream to the facility. With questionable future flow rates for fossil fuels, renewable and sustainable resources are of ever-increasing importance. The location relative to end users and fuel sources, as well as the scale of the contribution are metrics more relevant for operators, utilities, and siting commissions.

A well thought out design will consider all of these factors and yet, from a "whole systems" approach, may be inadequate. Failing to incorporate a net energy analysis may result in a project that is worthless from an energy perspective, and detrimental to the society that diverts resources supporting it. To evaluate energy production projects it helps to understand the concept of Energy Return On Energy Invested (EROEI).

A leading reason that our economies have grown robustly over the last few generations is precisely because our energy resources had unprecedentedly high EROEI ratios. As conventional fuels become more challenging to produce, their EROEIs have become noticeably lower. Relatively low EROEI challenges many renewable energy projects compared to most energy resources of the past century too.

What is EROEI?

Net energy analysis compares the amount of energy returned (produced) to the amount of energy invested (expended) to extract, transform, transport, and otherwise upgrade a raw energy resource into a form useable by society. Simple subtraction gives the *net energy*:

$$E_{net} = E_{returned} - E_{invested}$$

and the EROEI is obtained by dividing the energy returned by the energy invested:

$$EROEI = \frac{E_{returned}}{E_{invested}}$$

EROEI is similar to a concept familiar to every businessperson – *return on investment,* or *ROI*. Every investor knows of the importance of a positive ROI. Maintaining a positive EROEI is just as important for energy producers, and for society as a whole. (Some analysts use the shorter term *EROI.* The longer *EROEI* is used here to avoid the misconception that this is *energy returned on money invested*).

Why EROEI?

Net energy analysis has several advantages over standard economic analysis:

1. It assesses energy resources instead of the financial cost of those resources, and is therefore immune to the effects of market imperfections, such as tax credits, resource subsidies and mandates, that may distort monetary data.
2. Because goods and services are produced from the conversion of energy into useful work, net energy is a measure of the potential to do useful work in economic systems.
3. Net energy can be used to rank energy supply technologies according to their potential abilities to do useful work in the economy.

Illustration 1: Futility

The concept of net energy is easily understood; you can not expend more energy in the pursuit of energy than the resultant energy contains. A car owner would walk if the filling station were more than a tank away, just as a cheetah would perish if its prey offered fewer calories than the chase required. An energy expenditure equal to the energy obtained - simple refueling - would be pointless too. It is the surplus energy that allows the driver to travel and the cheetah to live another day. It is the surplus of energy that is worth pursuing. And so it is for any energy acquisition.

"*In nature, there are neither rewards nor punishments... there are consequences.*"
- Robert Ingersoll

Societies with access to energy sources with a large net energy surplus have an economic advantage over societies that use lower quality energy sources. A lower net energy 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. It is the high net energy that has been available to contemporary society over the past several decades that has supported a powerful military, abundant food choices, growth of the arts, enabled modern healthcare, provided ample leisure opportunities, investment growth, retirement, and much more that is now take for granted.

How to maximize EROEI?

There are two options for increasing the EROEI on an energy project:

1. Raise the amount of energy produced, or
2. Lower the energy expended to build, operate, and eventually decommission the facility.

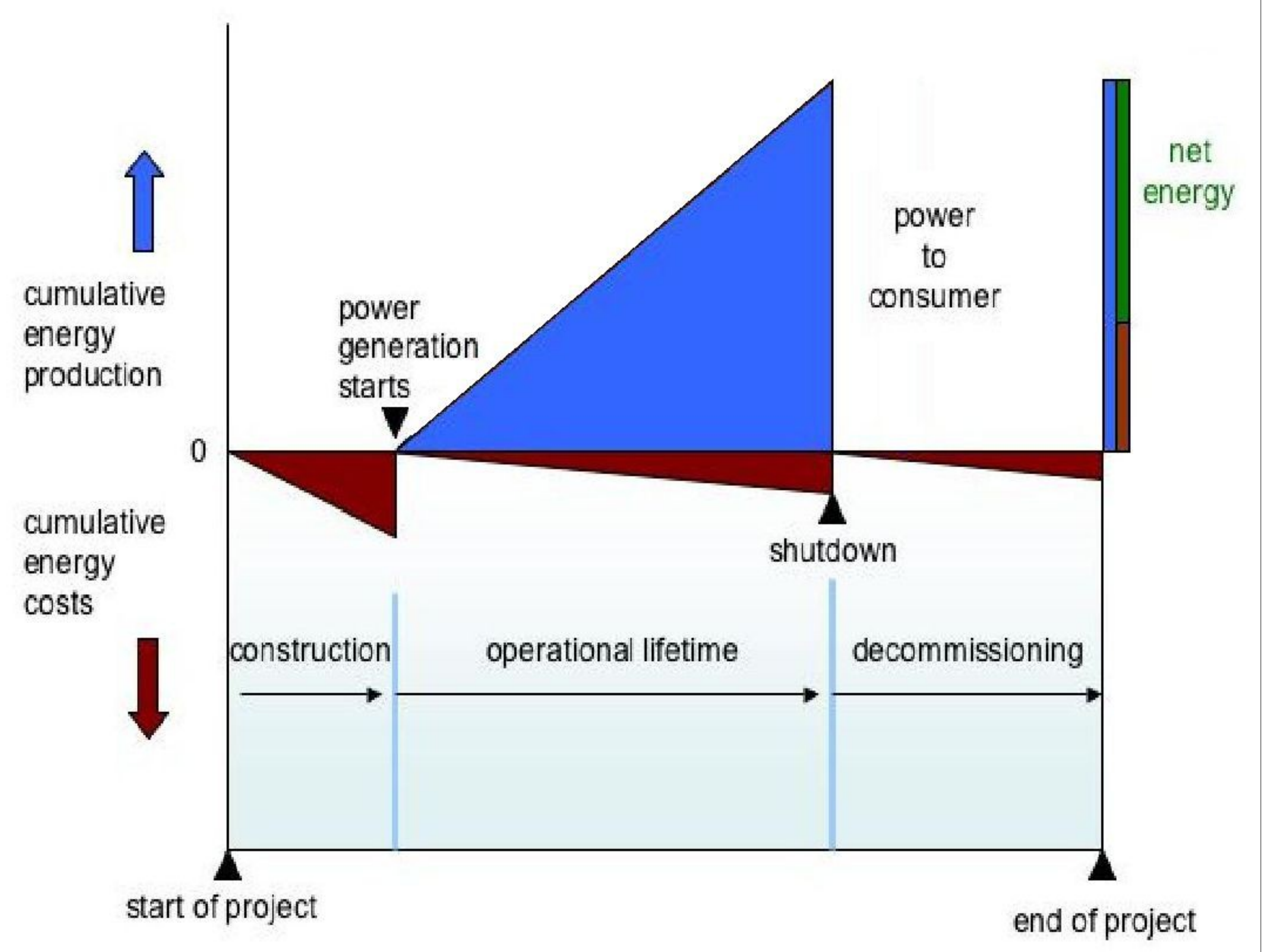

Illustration 2: Maximizing the energy produced while minimizing the energy to build, operate, and decommission a facility increases the net energy.

Siting energy projects can affect the net energy of the project's EROEI in numerous ways, for example:

- A biomass facility obtains the fuel it consumes within a given radius of the facility. If the biomass plant is sited near a border that restricts transportation, such as a water body without bridges or a political boundary that imposes transport restrictions (say to limit an insect infestation), the transport distance will increase. In a corner town such a Vernon, the radius could double if interstate transport were curtailed from New Hampshire and Massachusetts. This is to be expected in a small state where a larger portion of the land is nearer a potentially limiting border.

- Solar PV has a precipitous decline in production when the panels have even a small covering of leaves, snow, dust, etc. Avoiding sites where these obscurants are known to be present will significantly increase the energy production or the facility over its lifetime.
(A recently completed PV farm in southern Vermont is across the street from an active sand and gravel pit. Extended dry weather - with associated dust levels - requires either less than optimal power production or additional maintenance [energy] to clean the panels).
- Hydropower facilities have been sited in Vermont for centuries. Since the first resources exploited tend to be the highest quality ones with the least energy cost for exploitation, these existing locations are likely to offer the greatest net energy. Existing permitting and compliance requirements may be limiting many prospective developers to other, less energy profitable sites. While many new small hydro plants can have a reasonably high EROEI, it is typically considerably less than the historic sites.
- Large wind generators are more efficient as they can reach higher above the turbulent air near the ground, and reach up into the winds with higher speed. Similar to hydropower, sites that can accommodate larger sized generators are likely to have higher EROEIs. While there are many social and environmental concerns with wind generated power, especially the larger proposed towers, sites that work well for the larger towers usually offer substantially higher net energy.

A complete net energy analysis of a project would also consider the energy opportunity cost of the loss of the next best alternative use for that site. For example, if a facility were to displace farming activities, it may very well increase overall energy use by requiring greater transport of agricultural products. In this case, there may also be an increase in energy consumption to utilize marginal lands for the displaced farming operations.

The choice of system boundaries is perhaps the most important and challenging aspects of performing a net energy analysis. The parameters used should be specified so like comparisons between competing sites, or competing uses of a particular site, can be made. And with the boundaries defined, comparisons between different types of projects at different locations can also be made. This could help the state adopt energy policies that are more in line with energy realities than energy desires.

Unfortunately, many of the new energy prospects in Vermont (as well as most of the world) have much lower EROEIs than what we have become accustomed to. Maximizing the net energy from these marginal energies is essential to avoid harmful consequences to society.

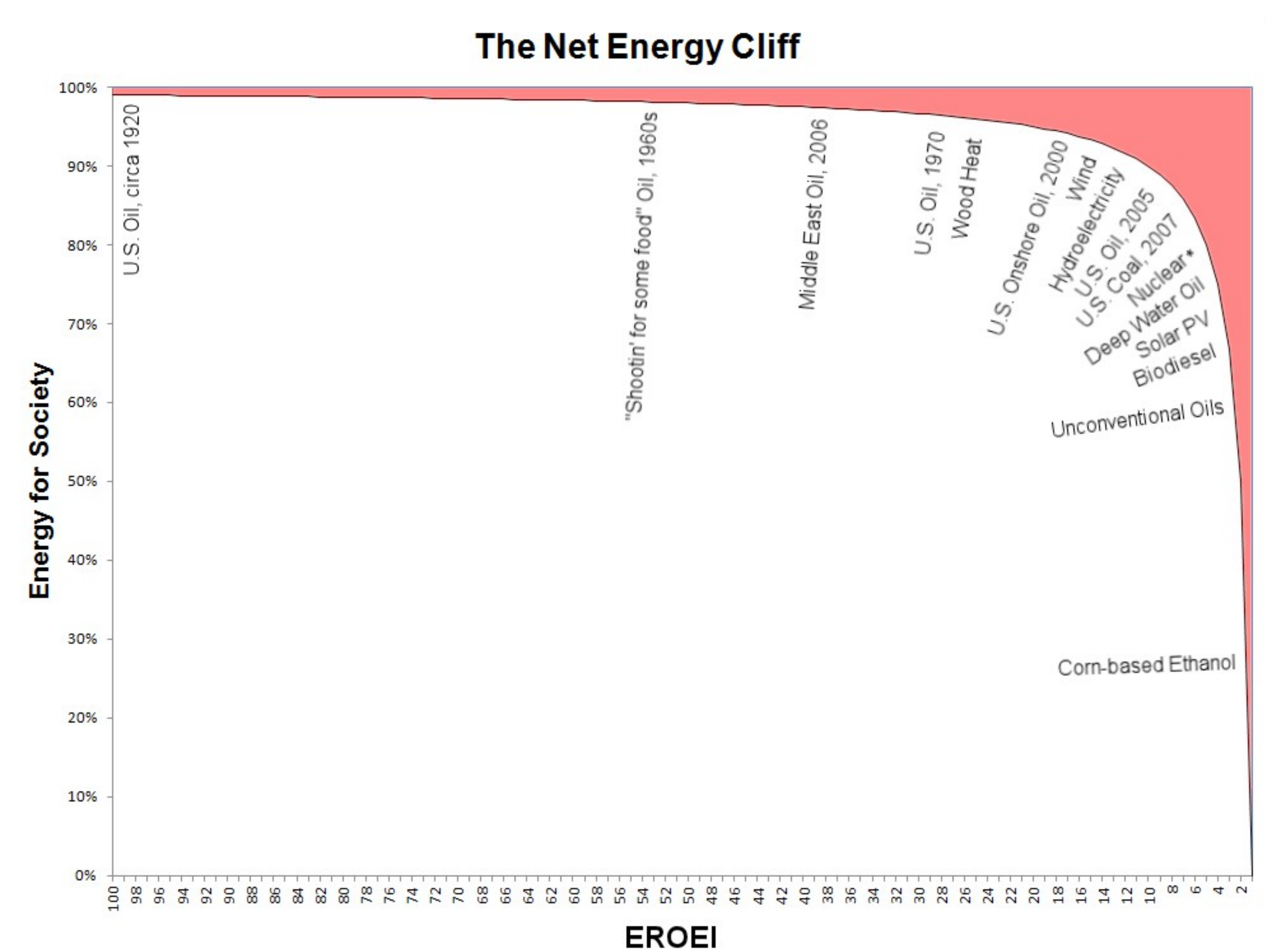

Illustration 3: The exponential relation between net energy and EROEI creates a sharp bend at roughly 8. Due to the asymptotic nature of the curve at high er EROEIs, there is little difference in the actual flow of net energy delivered. The corollary is that processes with EROEIs below 8 result in vastly different flows of net energy.

"We are caught in a paradox; the energies of the future have an EROEI too low for them to sustain a society complex enough to produce them."