

The Catch-22 of Energy Storage



Pick up a research paper on battery technology, fuel cells, energy storage technologies or any of the advanced materials science used in these fields, and you will likely find somewhere in the introductory paragraphs a throwaway line about its application to the storage of renewable energy. Energy storage makes sense for enabling a transition away from fossil fuels to more intermittent sources like wind and solar, and the storage problem presents a meaningful challenge for chemists and materials scientists... Or does it?

Guest Post by John Morgan. *John is Chief Scientist at a Sydney startup developing smart grid and grid scale energy storage technologies. He is Adjunct Professor in the School of Electrical and Computer Engineering at RMIT, holds a PhD in Physical Chemistry, and is an experienced industrial R&D leader. You can follow John on twitter at [@JohnDPMorgan](#). First published in [Chemistry in Australia](#).*

Several recent analyses of the inputs to our energy systems indicate that, against expectations, energy storage cannot solve the problem of intermittency of wind or solar power. Not for reasons of technical performance, cost, or storage capacity, but for something more intractable: there is not enough surplus energy left over after construction of the generators and the storage system to power our present civilization.

The problem is analysed in an important paper by Weißbach *et al.*¹ in terms of energy returned on energy invested, or EROEI – the ratio of the energy produced over the life of a power plant to the energy that was required to build it. It takes energy to make a power plant – to manufacture its components, mine the fuel, and so on. The power plant needs to make at least this much energy to break even. A break-even powerplant has an EROEI of 1. But such a plant would be pointless, as there is no energy surplus to do the useful things we use energy for.

There is a minimum EROEI, greater than 1, that is required for an energy source to be able to run society. An energy system must produce a surplus large enough to sustain things like food production, hospitals, and universities to train the engineers to build the plant, transport, construction, and all the elements of the civilization in which it is embedded.

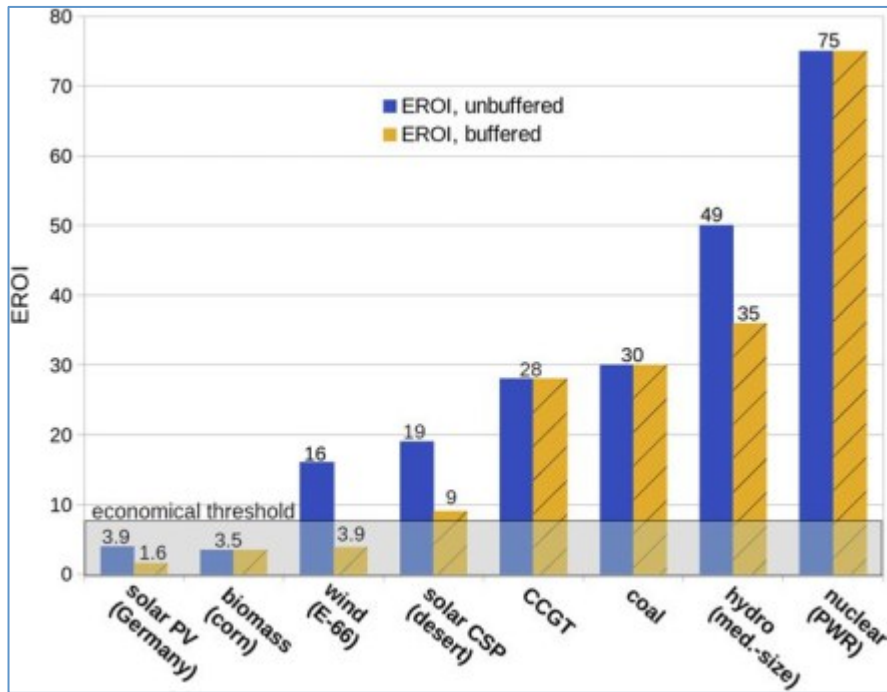
Origins of EROI

The concept of EROI was introduced by US fisheries ecologist Charles Hall, who noted that the energy a predator gained from eating prey had to exceed the energy expended in catching it. In 1981, Hall applied this net energy analysis to our own power generation activities, charting the decline of the EROI of US oil as ever more drilling was required to yield a given quantity, and suggesting the possibility that oil may one day take more energy to extract than it yields. Hall and others have since estimated the EROI for various power sources, a difficult analysis that requires identification of all energy inputs to power production.

EROI is a fundamental thermodynamic metric on power generation. Net energy analysis affords high-level insights that may not be evident from looking at factors such as energy costs, technological development, efficiency and fuel reserves, and sets real bounds on future energy pathways. It is unfortunately largely absent from energy and climate policy development.

For countries like the US and Germany, Weißbach *et al.* estimate this minimum viable EROEI to be about 7. An energy source with lower EROEI cannot sustain a society at those levels of complexity, structured along similar lines. If we are to transform our energy system, in particular to one without climate impacts, we need to pay close attention to the EROEI of the end result.

The EROEI values for various electrical power plants are summarized in the figure. The fossil fuel power sources we're most accustomed to have a high EROEI of about 30, well above the minimum requirement. Wind power at 16, and concentrating solar power (CSP, or solar thermal power) at 19, are lower, but the energy surplus is still sufficient, in principle, to sustain a developed industrial society. Biomass, and solar photovoltaic (at least in Germany), however, cannot. With an EROEI of only 3.9 and 3.5 respectively, these power sources cannot support with their energy alone both their own fabrication and the societal services we use energy for in a first world country.



Energy Returned on Invested, from Weißbach et al., 1 with and without energy storage (buffering). CCGT

is closed-cycle gas turbine. PWR is a Pressurized Water (conventional nuclear) Reactor. Energy sources must exceed the “economic threshold”, of about 7, to yield the surplus energy required to support an OECD level society.

These EROEI values are for energy directly delivered (the “unbuffered” values in the figure). But things change if we need to store energy. If we were to store energy in, say, batteries, we must invest energy in mining the materials and manufacturing those batteries. So a larger energy investment is required, and the EROEI consequently drops.

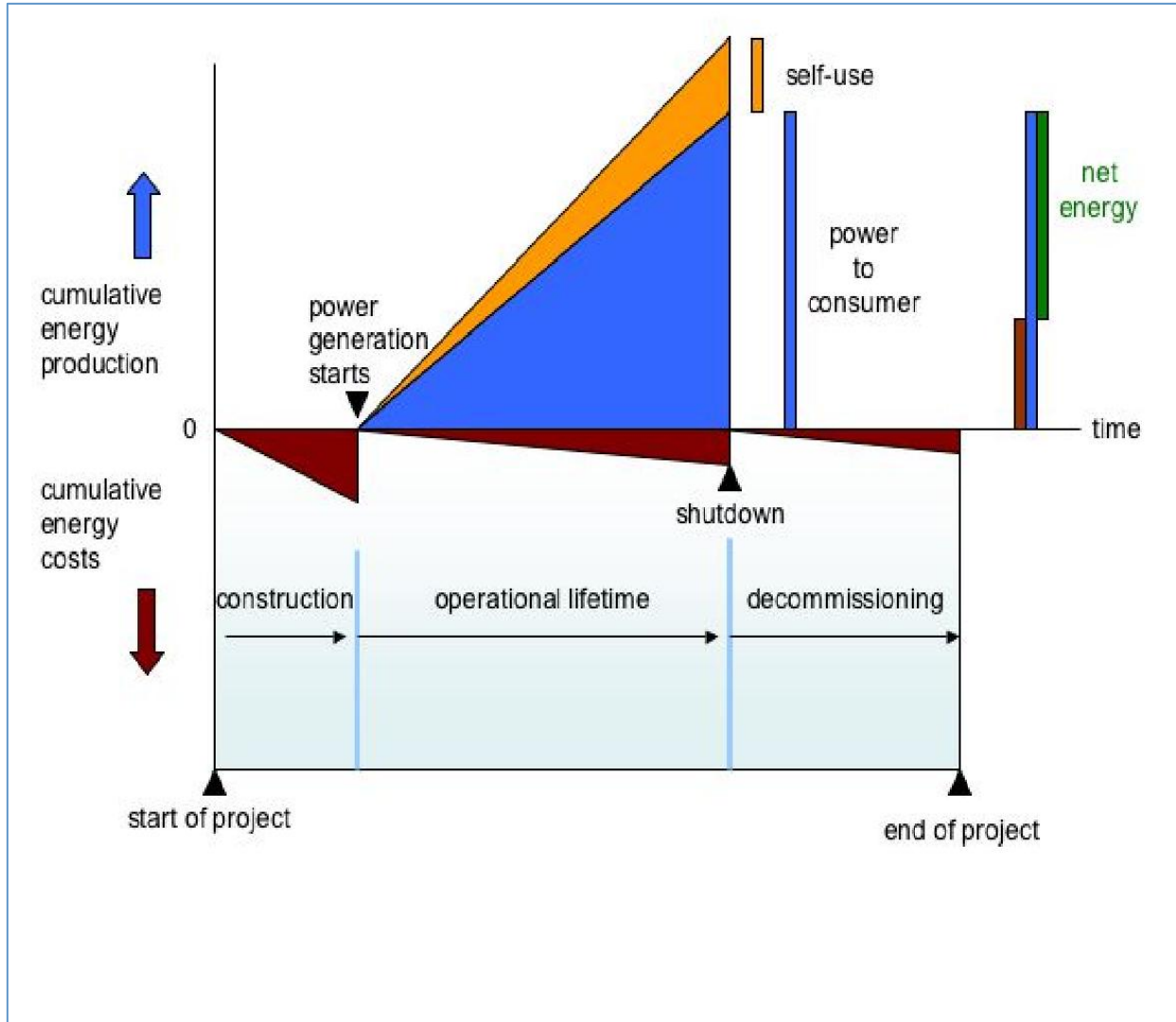
Weißbach *et al.* calculated the EROEIs assuming pumped hydroelectric energy storage. This is the least energy intensive storage technology. The energy input is mostly earthmoving and construction. It’s a conservative basis for the calculation; chemical storage systems requiring large quantities of refined specialty materials would be much more energy intensive. Carbajales-Dale *et al.*² cite data asserting batteries are about ten times more energy intensive than pumped hydro storage.

Adding storage greatly reduces the EROEI (the “buffered” values in the figure). Wind “firmed” with storage, with an EROEI of 3.9, joins solar PV and biomass as an unviable energy source. CSP becomes marginal (EROEI ~9) with pumped storage, so is probably not viable with molten salt thermal storage. The EROEI of solar PV with pumped hydro storage drops to 1.6, barely above breakeven, and with battery storage is likely in energy deficit.

This is a rather unsettling conclusion if we are looking to renewable energy for a transition to a low carbon energy system: we cannot use energy storage to overcome the variability of solar and wind power.

In particular, we can’t use batteries or chemical energy storage systems, as they would lead to much worse figures than those presented by Weißbach *et al.* Hydroelectricity is the only renewable power source that is unambiguously viable. However, hydroelectric capacity is not readily scaled up as it is restricted by suitable geography, a constraint that also applies to pumped hydro storage.

This particular study does not stand alone. Closer to home, Springer have just published a monograph, *Energy in Australia*,³ which contains an extended discussion of energy systems with a particular focus on EROEI analysis, and draws similar conclusions to Weißbach. Another study by a group at Stanford² is more optimistic, ruling out storage for most forms of solar, but suggesting it is viable for wind. However, this viability is judged only on achieving an energy surplus (EROEI>1), not sustaining society (EROEI~7), and excludes the round trip energy losses in storage, finite cycle life, and the energetic cost of replacement of storage. Were these included, wind would certainly fall below the sustainability threshold.



It's important to understand the nature of this EROEI limit. This is not a question of inadequate storage capacity – we can't just buy or make more storage to make it work. It's not a question of energy losses during charge and discharge, or the number of cycles a battery can deliver. We can't look to new materials or technological advances, because the limits at the leading edge are those of earthmoving and civil engineering. The problem can't be addressed through market support mechanisms, carbon pricing, or cost reductions. This is a fundamental energetic limit that will likely only shift if we find less materially intensive methods for dam construction.

This is not to say wind and solar have no role to play. They can expand within a fossil fuel system, reducing overall emissions. But without storage the amount we can integrate in the grid is greatly limited by the stochastically variable output. We could, perhaps, build out a generation of solar and wind and storage at high penetration. But we would be doing so on an endowment of fossil fuel net energy, which is not sustainable. Without storage, we could smooth out variability by building redundant generator capacity over large distances. But the additional infrastructure also forces the EROEI down to unviable levels. The best way to think about wind and solar is that they can reduce the emissions of fossil fuels, but they cannot eliminate them. They offer mitigation, but not replacement.

Nor is this to say there is no value in energy storage. Battery systems in electric vehicles clearly offer potential to reduce dependency on, and emissions from, oil (provided the energy is sourced from clean power). Rooftop solar power combined with four hours of battery storage can usefully timeshift peak electricity demand,³ reducing the need for peaking power plants and grid expansion. And battery technology advances make possible many of our recently indispensable consumer electronics. But what storage can't do is enable significant replacement of fossil fuels by renewable energy.

If we want to cut emissions and replace fossil fuels, it can be done, and the solution is to be found in the upper right of the figure. France and Ontario, two modern, advanced societies, have all but eliminated fossil fuels from their electricity grids, which they have built from the high EROEI sources of hydroelectricity and nuclear power. Ontario in particular recently burnt its last tonne of coal, and each jurisdiction uses just a few percent of gas fired power. This is a proven path to a decarbonized electricity grid.

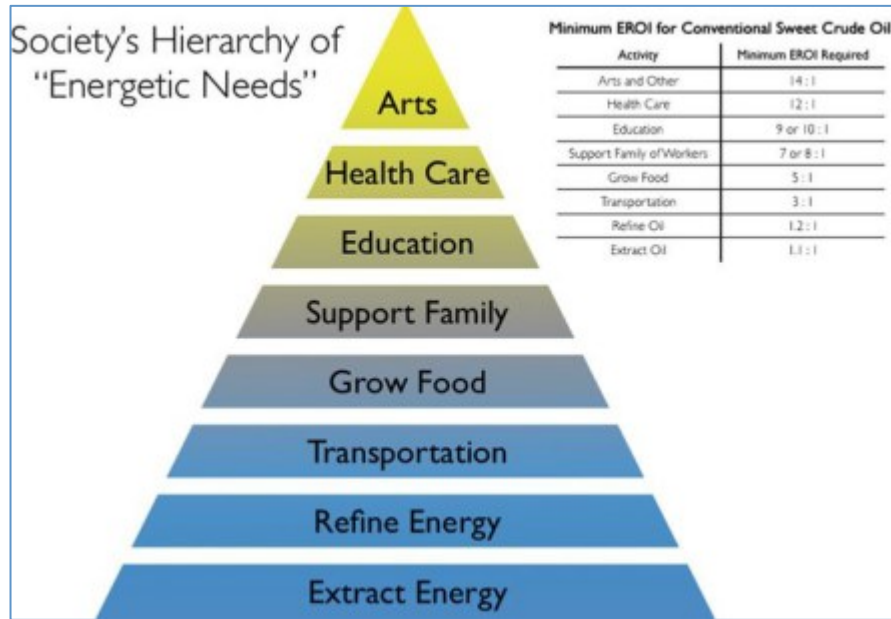
But the idea that advances in energy storage will enable renewable energy is a chimera – the Catch-22 is that in overcoming intermittency by adding storage, the net energy is reduced below the level required to sustain our present civilization.

When this article was published in *CiA* some readers had difficulty with the idea of a minimum societal EROI. Why can't we make do with any positive energy surplus, if we just build more plant? Hall⁴ breaks it down with the example of oil:

Think of a society dependent upon one resource: its domestic 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. If it were 1.2:1 you could also refine it and look at it, 1.3:1 also distribute it to where you want to use it but all you could do is look at it. Hall et al. 2008 examined the EROI required to actually run a truck and found that if the energy included was enough to build and maintain the truck and the roads and bridges required to use it, one would need at least a 3:1 EROI at the wellhead.

Now if you wanted to put something in the truck, say some grain, and deliver it, that would require an EROI of, say, 5:1 to grow the grain. If 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 say 7 or 8:1 to support their families. If the children were to be educated you would need perhaps 9 or 10:1, have health care 12:1, have arts in their life maybe 14:1, and so on. Obviously to have a modern civilization one needs not simply surplus energy but lots of it, and that requires either a high EROI or a massive source of moderate EROI fuels.

The point is illustrated in the EROI pyramid.⁴ (The *blue* values are published values: the *yellow* values are increasingly speculative.)



Finally, if you are interested in pumped hydro storage, a [previous Brave New Climate article](#) by Peter Lang covers the topic in detail, and the comment stream is an amazing resource on the operational characteristics and limits of this means of energy storage.

References

- 1 Weißbach *et al.*, *Energy* 52 (2013) 210. [Preprint available here.](#)
- 2 Carbajales-Dale *et al.*, *Energy Environ. Sci.* DOI: 10.1039/c3ee42125b
- 3 Graham Palmer, *Energy in Australia: Peak Oil, Solar Power, and Asia's Economic Growth*; Springer 2014.
- 4 Pedro Prieto and Charles Hall, *Spain's Photovoltaic Revolution*, Springer 2013.