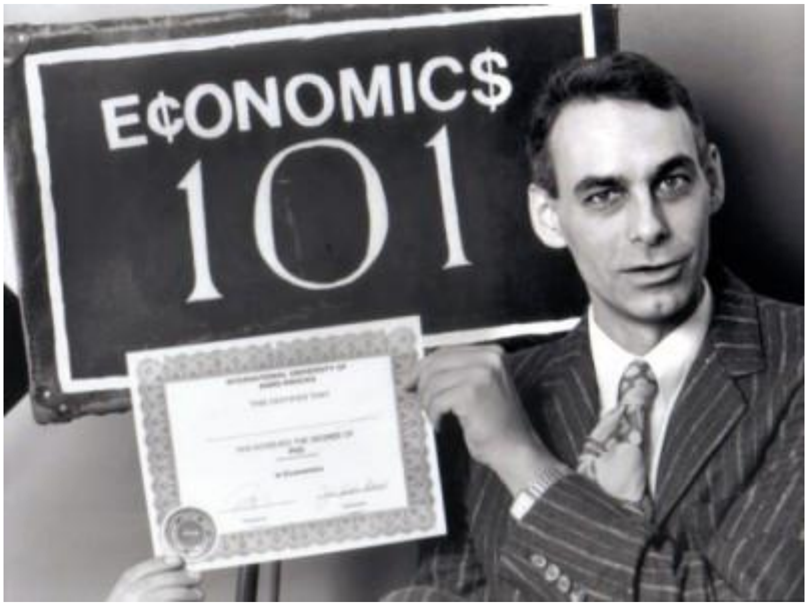
Wind Power: the Wick Just Ain’t Worth the Candle: Energy Return vs Energy Invested Explained

June 8, 2016 by stopthesethings 1 Comment



In most scenarios involving the sane, equipped with cool, analytical heads, the economic choices we make (and the policies that surround, support or reflect them) are driven by a simple equation: that the economic cost should be outweighed by the benefits on offer.

In less than a figurative heartbeat, energy policy has been hijacked by energy market illiterates like Environment Minister Greg Hunt (a lawyer) and, among the ALP, former Union Reps , like Electricity Bill Shorten andMark Butler (likewise equipped with law degrees and bereft of common sense). The result – brought into sharp focus in Australia’s wind farm capital, South Australia – is spiralling retail power prices and a grid killing,chaotic power supply (with worse to come). All of which proves that Union hacks and lawyers are best kept well away from anything that is supposed to move, whir or hum: especially where lives, businesses and households depend on the outcome.

In short, electricity grids are best designed and run by Engineers; markets are best designed and run by Economists. In this rather technical offering we’ll hand over to Euan Mearns to explain just why wind power will never amount to a meaningful power source.

ERoEI for Beginners

Euan Mearns

Energy Matters

25 May 2016

The Energy Return on Energy Invested (ERoEI or EROI) of any energy gathering system is a measure of that system’s efficiency. The concept was originally derived in ecology and has been transferred to analyse human industrial society. In today’s energy mix, hydroelectric power ± nuclear power have values > 50. At the other end of the scale, solar PV and biofuels have values <5.

It is assumed that ERoEI >5 to 7 is required for modern society to function. This marks the edge of The Net Energy Cliff and it is clear that new Green technologies designed to save humanity from CO2 may kill humanity through energy starvation instead. Fossil fuels remain comfortably away from the cliff edge but march closer to it for every year that passes. The Cheetah symbolises an energy system living on the edge.

I first came across the concept of Energy Return on Energy Invested (ERoEI) several years ago in Richard Heinberg’s book The Party’s Over [1]. I had never contemplated the concept before and I was immediately struck by its importance. If we used more energy to get the energy we need to survive then we will surely perish.

Shortly thereafter I joined The Oil Drum crew and had the great pleasure of meeting Professor Charles Hall, the Godfather of ERoIE analysis who developed the concept during his PhD studies and first published the term in 1977. ERoEI would become a point of focus for Oil Drum posts. Nate Hagens and David Murphy, both Oil Drum crew, have now completed PhDs on ERoEI analysis aided and abetted by the conversation that the Oil Drum enabled.

But recently I have received this via email from Nate:

10 years on the same questions and issues are being addressed – (and maybe 40 years on for Charlie). A new tier of people are aware of EROI but it is still very fringe idea?

Are we wrong to believe that ERoEI is a fundamentally important metric of energy acquisition or is it simply that the work done to date is not sufficiently rigorous or presented in a way that economists and policy makers can understand. At this point I will cast out a bold idea that money was invented as a proxy for energy because ERoEI was too complex to fathom.

And I have this via email from my friend Luis de Sousa who did not like the Ferroni and Hopkirk paper [3] nor my post reviewing it:

On the grand scheme of things: PV ERoEI estimates range from 30 down to 0.8. Before asking the IEA (or whomever) to start using ERoEI, the community producing these estimates must come down to a common, accepted methodology for its assessment. As it stands now, EROEI is not far from useless to energy policy.

And while I disagree with Luis on a number of issues, on this statement I totally concur. So what has gone wrong? Professor Hall points out that it is not the concept that is at fault but non-rigorous application of certain rules that must be followed in the analysis. In this post I will endeavour to review the main issues and uncertainties, and while it is labelled “for Beginners”, I will flirt with an intermediate level of complexity.

What is ERoEI?

ERoEI is simply the ratio of energy gathered to the amount of energy used to gather the energy (the energy invested):

ERoEI = energy gathered / energy invested

Note that in common vernacular the term energy production is used. But in fact humans produce very little energy, but what distinguishes us from other species is that we have become very efficient at gathering energy that already exists and building machines that can convert the energy to goods (motor cars, televisions and computers) and services (heat and light and mobility) that collectively define our wealth.

This began by gathering fire wood and food and progressed to gathering coal, oil and natural gas. This led to gathering U and Th and learning how to convert this to enormous amounts of thermal and electrical energy. And now we attempt to gather solar energy through photovoltaics, wind turbines and liquid biofuels.

The prosperity of humanity depends upon the efficiency with which we gather energy. 100 years ago and 50 years ago we hit several jackpots in the form of vast coal, oil and gas deposits. These were so rich and large that energy virtually spewed out of them for next to no energy or financial investment. Examples include the Black Thunder coal field (USA), the Ghawar oil field (Saudi Arabia) and the Urengoy gas field (Russia) to name but a few. But these supergiant deposits are now to varying degrees used up. And as global population has grown together with expectations of prosperity that are founded on energy gathering activities, humanity has had to expand its energy gathering horizons to nuclear power, solar power and energy from waste. And it is known that some of the strategies deployed have very low ERoEI, for example corn ethanol is around 1 to 2 [2] and solar PV between 1 and 5 [2,3] depending upon where it is sited and the boundaries used to estimate energy costs. Consider that an ERoEI greater than 5 to 7 is deemed necessary to sustain the society we know (see below) then it is apparent that we may be committing energy and economic suicide by deliberately moving away from fossil fuels.

Low ERoEI is expected to correlate with high cost and in the normal run of events investors should steer clear of such poor investment returns. But the global energy system is now dictated by climate concern, and any scheme that portends to produce energy with no CO2 is embraced by policymakers everywhere and financial arrangements are put in place to enable deployment, regardless of the ERoEI.

Net Energy

Net energy is the close cousin of ERoEI being the surplus energy made available to society from our energy gathering activities. It is defined simply as:

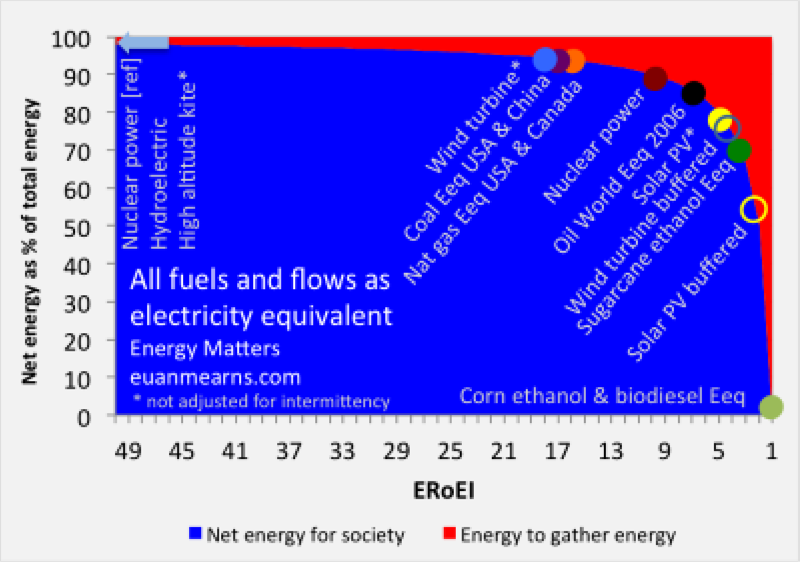
net energy = ERoEI-1

If we have ERoEI = 1, then the net energy is zero. We use as much energy to gather energy as energy gathered. The “1” always represents the energy invested. If ERoEI falls below 1 we end up with an energy sink. Low ERoEI systems are effectively energy conversions where it may be convenient or politically expedient for us to convert one energy carrier into another with little or no energy gain. Corn ethanol is a good example where fertiliser, natural gas, diesel, electricity, land, water and labour gets converted into ethanol, a liquid fuel that can go in our cars. But it does leave the question why we don’t just use liquefied natural gas as a transport fuel in the first place and save on all the bother that creating corn ethanol involves?

The Net Energy Cliff

Many years ago during a late night blogging session on The Oil Drum, and following a post by Nate Hagens, I came up with a way of plotting ERoEI that for many provided an instantaneous understanding of its importance. The graph has become known as the net energy cliff, following nomenclature of Nate and others.

Figure 1 The Net Energy Cliff shows how with declining ERoEI society must commit ever larger amounts of available energy to energy gathering activities. Below ERoEI = 5 to 7 such large numbers of people would be working for the energy industries that there would not be enough people left to fill all the other positions our current altruistic society offers.



The graph plots net energy as a % of ERoEI and shows how energy for society (in blue) varies with ERoEI. In red is the balance being the energy used to gather energy.

It is the shape of the boundary between blue and red that is of interest. If we start at 50 and work our way down the ERoEI scale moving to the right, we see that energy invested (red) increases very slowly from 2% at ERoEI=50 to 10% at ERoEI=10. But beyond 10, the energy invested increases exponentially to 20% at ERoEI=5 and to 50% at ERoEI=2. At ERoEI = 1, 100% of the energy used is spent gathering energy and we are left with zero gain.

This is important because it is the blue segment that is available for society to use. This pays for infrastructure, capital projects, mining and manufacturing, agriculture, food processing and retailing, education, healthcare and welfare, defence and government. In fact it is the amount of net energy that powers everything in society as we know it today. The net energy from past energy gathering has accumulated to create what we identify as capital and wealth. Nothing could be more important, and yet the concept remains on the fringe of energy policy and public awareness. One of the problems is that measuring ERoEI consistently is difficult to do. One problem is retaining objectivity. If you manufacture PV modules you are unlikely to claim that the ERoEI is less than 5, and there are a multitude of variables that can be adjusted to provide whatever answer is deemed to be good.

This depiction of Net Energy is also useful in defining that all energy and labour can be divided into energy and labour used in the energy industries and the industries that support them and energy and labour used by society that consumes the surpluses produced by the energy industries. More on this later.

It has been assumed by many that ERoEI > 7 was required for the industrial society we live in to function although the source of this assertion remains elusive. But the blue-red boundary provides a clear visual picture of why this may be so. Below 7 and humanity falls off the net energy cliff where a too large portion of our human resources and capital need to be invested in simply staying alive to the detriment of the services provided by net energy such as health care, education and pensions.

System boundaries

Energy Inputs

One of the main uncertainties in ERoEI analysis is where to set the system boundaries. I have not found a simple text or graphic that adequately explains this vital concept.

Figure 2 A simplified scheme for an energy system divided into construction, operation and decommissioning with accumulated inputs and outputs. Graphic from this excellent presentation by Prieto and Hall

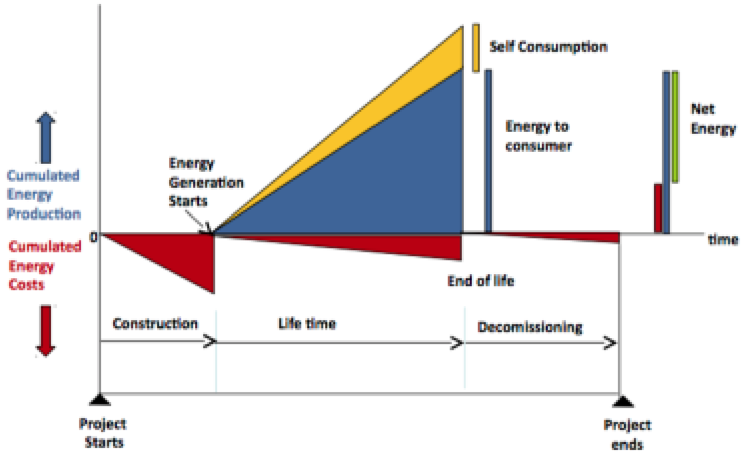


Figure 2 provides an illustration of the life cycle of an energy system divided into three stages 1) construction, 2) operation and 3) decommissioning. Energy inputs occur at each stage but energy outputs will normally only occur during the operational phase. It should be straight forward to account for all the energy inputs and outputs to calculate ERoEI but it isn't. For example many / most of our energy systems today are still operational. We do not yet have final numbers for oil produced from single fields. And the decommissioning energy costs are not yet known. Most wind turbines ever built are still operational, producing energy and the ultimate energy produced will depend upon how long they last. And then perhaps some turbines are offered a new lease of life via refurbishment etc.

Energy inputs can normally be divided as follows [2]:

1. On site energy consumption
2. Energy embedded in materials used
3. Energy consumed by labour
4. Auxiliary services

Moving from 1 to 4 may be considered expansion of the ERoEI boundary where energy embedded in materials and energy consumed by labour are added to on-site energy consumption. There follows some examples of ambiguity that remains in deciding what to include and what to leave out. These examples are given for purely illustrative purposes.

No one should question that the electricity used by a PV factory should be included. But do you include electricity / energy used to heat or cool the factory? Or just the electricity used to run the machines? Including heating or cooling introduces a site specific variable which will mean that the energy inputs to a PV panel may vary according to where it was manufactured. There are many such site specific variables like transport, energy costs, labour energy costs, health and safety energy costs etc, which when combined in our globalised market has made China the lowest energy cost centre for PV manufacturing today.

It is clear to me that the energy cost of all materials used in the energy production process must be included. And this should include materials consumed at the construction, operational and decommissioning stages. In the oil industry this will include the materials in the oil platform, the helicopter and the onshore office. In the solar PV industry this will include all the materials in the panels, in the factory, and in the support gantries and inverter. As a general rule of thumb, massive energy gathering systems that contain a huge amount of materials will have reduced ERoEI because of the energy embedded in those materials.

It is also clear to me that the energy cost of all labour should be included in the ERoEI analysis for construction, operation and decommissioning. But it is far less clear how it should be calculated. The energy consumed by labourers varies greatly from country to country and with time. Should we just include the energy consumed by a labourer on his/her 8 hour shift? Or should we include the full 24/7? Should the energy consumed by labourers getting to and from work be included? – of course it should. Should the energy consumed on vacations be included? – not so clear. And how can any of this be calculated in the first place?

The standard way to calculate the energy cost of labour is to examine the energy intensity of GDP. For most countries, the total amount of primary energy consumed is roughly known and the total GDP is known. This provides a means of converting MJ to $ and we can then look at the $ earnings of a labourer to get a rough handle on the notional energy use that may be attributed to his salary scale. This is far from perfect but is currently the only practical method available.

Auxiliary services become even more difficult to differentiate. Some argue that the energy cost of the highway network, power distribution network and services like schools and hospitals should be pro-rated into new energy production systems. My own preference is to generally exclude these items from an ERoEI analysis unless there are good reasons for not doing so. I think it is useful to go back to the question are we expending energy on energy gathering or are we expending energy on society and most of the infrastructure upon which new energy systems depend was built using prior surpluses allocated to society. In my view it becomes too complex to pro-rate these into an ERoEI calculation. The power grid delivering power to the PV factory already existed. But if a new power line needs to be built to export renewable electricity then that should be accounted for.

Energy Outputs

One might imagine that measuring the energy output would be more straightforward, but it is not so. Many earlier studies on the ERoEI of oil set a boundary at the well head or on site tank farm. And it is relatively straightforward to measure the oil production from a field like Forties in the North Sea. But crude oil itself is rarely used directly as a fuel. It is the refined products that are used. To actually use the oil we need to ship or pipe it to shore and then on to a refinery. The energy cost of transport may add 10% to energy inputs and refining may add yet another 10%. It has been suggested that one approach is to calculate ERoEI at Point of Use. Crude oil on an offshore platform is of no use to anyone. Gasoline in a filling station is what we want and all the energy inputs involved in getting the gasoline to the forecourt need to be counted.

But here we meet another dilemma. The refinery may produce paraffin and gasoline. The ERoEI of both are likely to be similar at the refinery gate. But the gasoline is burned in an engine to produce kinetic energy used for transport and in so doing about 70% of the energy is lost as waste heat. The paraffin may be burned in a stove with near 100% conversion efficiency to space heating. Do we reduce the ERoEI of gasoline by 70% to reflect energy losses during use?

This introduces the concept of energy quality where we know that final energy conversions are in three main forms 1) heat 2) motion and 3) electricity that has a myriad of different uses. Is it really possible to compare these very different energy outputs using the single umbrella of ERoEI? The routine followed by ERoEI analysts to date is to adjust ERoEI for energy quality though I'm unsure how that is done [2]. Another option that I like is to hypothetically normalise all outputs to a single datum, for example MWh of electricity (see below). But this again gets to a level of complexity that is beyond this blog post.

There are some other important energy quality factors. Dispatch for electricity is one. Producing a vast amount of electricity from wind on a stormy Sunday night has little to no value. While the ability to produce electricity on demand at 6 pm on a freezing Wednesday evening in January (NH) is of great value. Curtailed wind should clearly be deducted from wind energy produced in the ERoEI calculation. Just like the oil spilled from the Deep Water Horizon in the Gulf of Mexico should not be counted as oil produced from the Macondo field.

External environmental factors may also have to be considered as part of the energy quality assessment. It is clear that the oil spilled from the Deep Water Horizon had to be cleared up immediately and the energy cost of doing so almost bankrupted BP. But it is less clear that the energy cost of eliminating CO2 emissions needs to be borne by the energy production industries. For example, the cost of carbon capture and storage would fall on the consumer and not the energy producer.

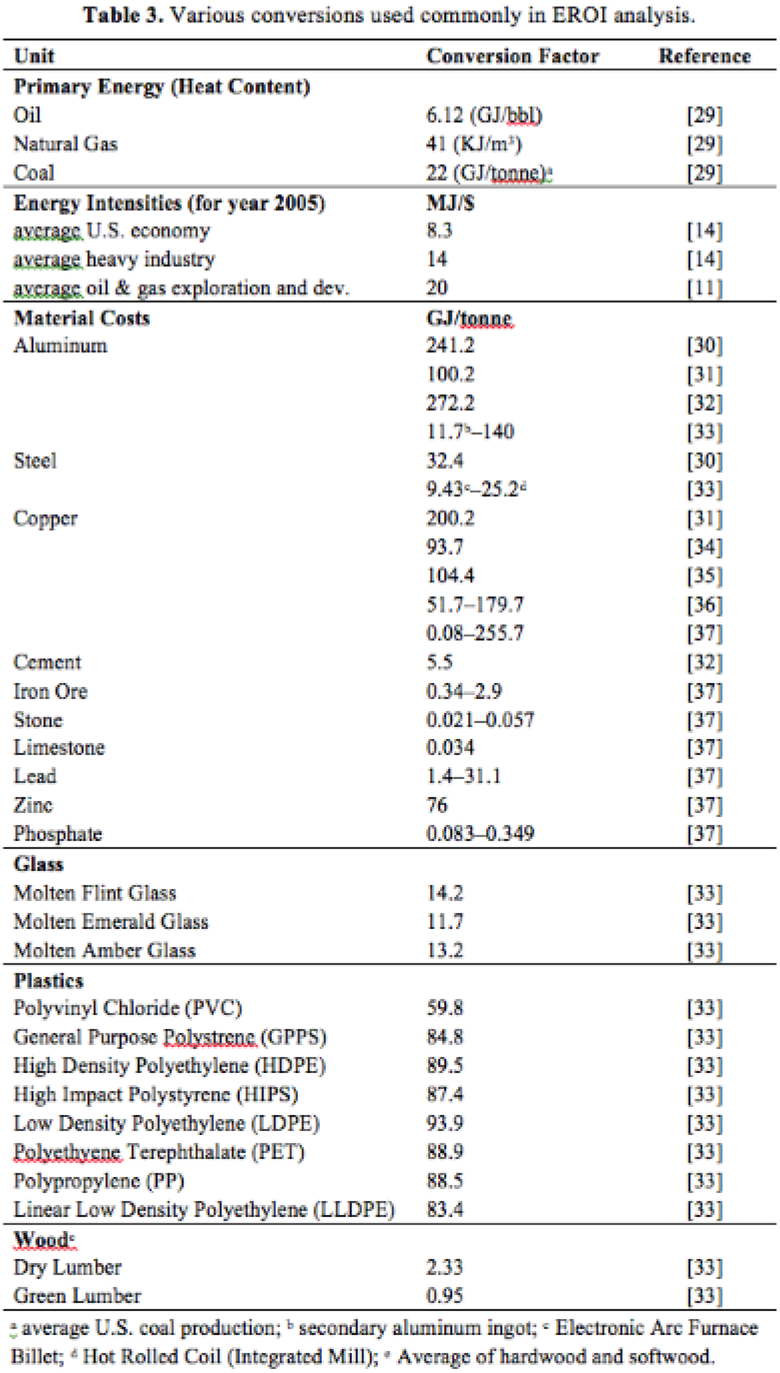


Table 3. Various conversions used commonly in EROI analysis.

Unit	Conversion Factor	Reference
Primary Energy (Heat Content)		
Oil	6.12 (GJ/bbl)	[29]
Natural Gas	41 (KJ/m^3)	[29]
Coal	22 (GJ/tonne)[a]	[29]
Energy Intensities (for year 2005)	**MJ/$**	
average U.S. economy	8.3	[14]
average heavy industry	14	[14]
average oil & gas exploration and dev.	20	[11]
Material Costs	**GJ/tonne**	
Aluminum	241.2	[30]
	100.2	[31]
	272.2	[32]
	11.7[b]–140	[33]
Steel	32.4	[30]
	9.43[c]–25.2[d]	[33]
Copper	200.2	[31]
	93.7	[34]
	104.4	[35]
	51.7–179.7	[36]
	0.08–255.7	[37]
Cement	5.5	[32]
Iron Ore	0.34–2.9	[37]
Stone	0.021–0.057	[37]
Limestone	0.034	[37]
Lead	1.4–31.1	[37]
Zinc	76	[37]
Phosphate	0.083–0.349	[37]
Glass		
Molten Flint Glass	14.2	[33]
Molten Emerald Glass	11.7	[33]
Molten Amber Glass	13.2	[33]
Plastics		
Polyvinyl Chloride (PVC)	59.8	[33]
General Purpose Polystrene (GPPS)	84.8	[33]
High Density Polyethylene (HDPE)	89.5	[33]
High Impact Polystyrene (HIPS)	87.4	[33]
Low Density Polyethylene (LDPE)	93.9	[33]
Polyethyene Terephthalate (PET)	88.9	[33]
Polypropylene (PP)	88.5	[33]
Linear Low Density Polyethylene (LLDPE)	83.4	[33]
Wood[e]		
Dry Lumber	2.33	[33]
Green Lumber	0.95	[33]

[a] average U.S. coal production; [b] secondary aluminum ingot; [c] Electronic Arc Furnace Billet; [d] Hot Rolled Coil (Integrated Mill); [e] Average of hardwood and softwood.

Using energy proxies

In ERoEI analysis direct energy use can normally be measured, for example gas and diesel used on an oil platform or the electricity used in a factory. But the indirect energy consumed by, for example materials and labour, are less easy to measure and are often based on proxies. It is nearly impossible to measure the energy embedded in an offshore oil platform. Instead the mass of steel and the number of man days of labour used in construction can be estimated and from these the energy expended and now embedded in the platform can be estimated.

As already discussed, the standard way of estimating the energy cost of labour is to use the energy intensity of GDP data from the countries in question combined with workers salaries.

For materials Murphy et al [2] provide this useful summary (Figure 3)

Figure 3 The estimated energy content of common materials [2]

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From this the most striking feature is the vast range within certain materials and between materials. For example aluminium ranges from 100 to 272 GJ/tonne. Steel 9 to 32 GJ/tonne. Part of this will be down to methodological differences in the way the numbers are derived. But part of it may be down to real differences reflecting different energy efficiencies of smelting plants.

ERoEI of Global Fuels and Energy Flows

So what is the current status of ERoEI in the global energy mix? Hall et al 2014 [4] provide the following summary table which is the foundation of the summary graph below.

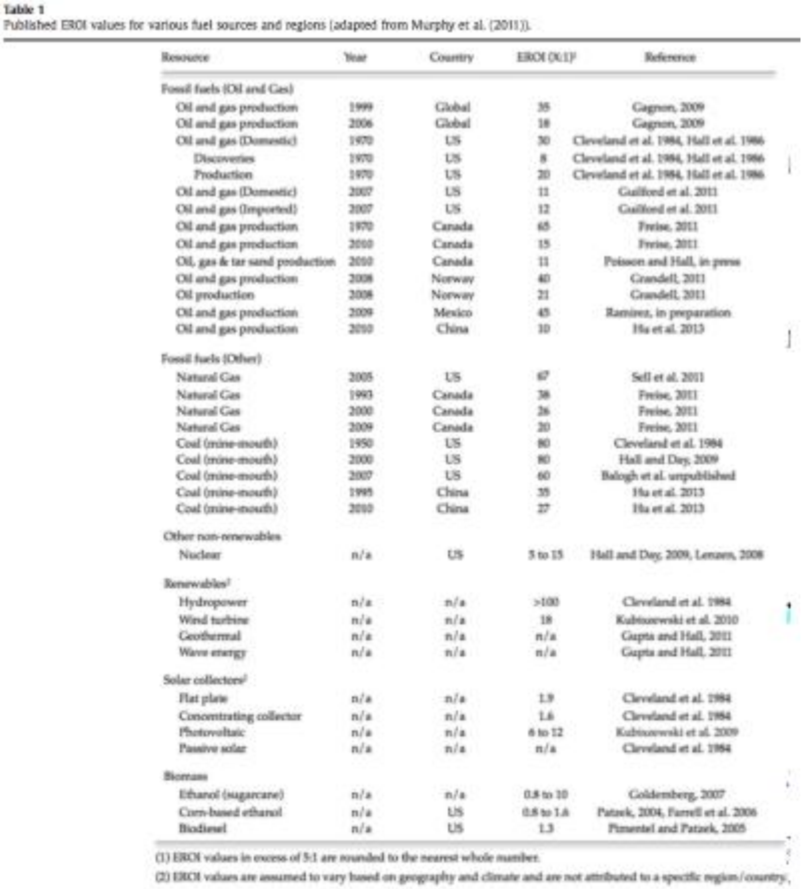

Table 1
Published EROI values for various fuel sources and regions (adapted from Murphy et al. (2011)).

Resource	Year	Country	EROI (X:1)[1]	Reference
Fossil fuels (Oil and Gas)				
Oil and gas production	1999	Global	35	Gagnon, 2009
Oil and gas production	2006	Global	18	Gagnon, 2009
Oil and gas (Domestic)	1970	US	30	Cleveland et al. 1984, Hall et al. 1986
Discoveries	1970	US	8	Cleveland et al. 1984, Hall et al. 1986
Production	1970	US	20	Cleveland et al. 1984, Hall et al. 1986
Oil and gas (Domestic)	2007	US	11	Guilford et al. 2011
Oil and gas (Imported)	2007	US	12	Guilford et al. 2011
Oil and gas production	1970	Canada	65	Freise, 2011
Oil and gas production	2010	Canada	15	Freise, 2011
Oil, gas & tar sand production	2010	Canada	11	Poisson and Hall, in press
Oil and gas production	2008	Norway	40	Grandell, 2011
Oil production	2008	Norway	21	Grandell, 2011
Oil and gas production	2009	Mexico	45	Ramirez, in preparation
Oil and gas production	2010	China	10	Hu et al. 2013
Fossil fuels (Other)				
Natural Gas	2005	US	67	Sell et al. 2011
Natural Gas	1993	Canada	38	Freise, 2011
Natural Gas	2000	Canada	26	Freise, 2011
Natural Gas	2009	Canada	20	Freise, 2011
Coal (mine-mouth)	1950	US	80	Cleveland et al. 1984
Coal (mine-mouth)	2000	US	80	Hall and Day, 2009
Coal (mine-mouth)	2007	US	60	Balogh et al. unpublished
Coal (mine-mouth)	1995	China	35	Hu et al. 2013
Coal (mine-mouth)	2010	China	27	Hu et al. 2013
Other non-renewables				
Nuclear	n/a	US	5 to 15	Hall and Day, 2009, Lenzen, 2008
Renewables[2]				
Hydropower	n/a	n/a	>100	Cleveland et al. 1984
Wind turbine	n/a	n/a	18	Kubiszewski et al. 2010
Geothermal	n/a	n/a	n/a	Gupta and Hall, 2011
Wave energy	n/a	n/a	n/a	Gupta and Hall, 2011
Solar collectors[2]				
Flat plate	n/a	n/a	1.9	Cleveland et al. 1984
Concentrating collector	n/a	n/a	1.6	Cleveland et al. 1984
Photovoltaic	n/a	n/a	6 to 12	Kubiszewski et al. 2009
Passive solar	n/a	n/a	n/a	Cleveland et al. 1984
Biomass				
Ethanol (sugarcane)	n/a	n/a	0.8 to 10	Goldemberg, 2007
Corn-based ethanol	n/a	US	0.8 to 1.6	Patzek, 2004, Farrell et al. 2006
Biodiesel	n/a	US	1.3	Pimentel and Patzek, 2005

(1) EROI values in excess of 5:1 are rounded to the nearest whole number.
(2) EROI values are assumed to vary based on geography and climate and are not attributed to a specific region/country.

Figure 4 Summary of the ERoEI for a range of fuels and renewable energies.

Figure 5 Placing main energy sources on The Net Energy Cliff framework shows that hydro-electric power, high altitude kites and perhaps nuclear power have very high ERoEI and embracing these technologies may prevent humanity from falling off the Net Energy Cliff. The new bright Green energies of bio-fuels, solar PV and buffered wind (see below) are already over the cliff edge and if we continue to embrace these technologies human society may perish as we expend too large a portion of our energy endowment simply getting energy. Fossil fuels remain comfortably to the left of the cliff edge but are marching ever closer towards it with every year that passes. Eeq = electricity equivalent (see below).

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In order to compare fossil fuels with electricity flows on a single diagram it is essential to reduce all of the energy types to a common datum. Its quite simply not valid to compare the ERoEI of coal at the mine mouth with nuclear power since in converting the coal to electricity, much of the energy is lost. The easiest route is to rebase everything to electricity equivalent (Eeq) where I follow the BP convention and adjust the ERoEI of fossil fuels by a factor of 0.38 to account for energy conversion losses in a modern power station.

In an earlier thread, Owen posted a link to a pre-print by Weisbach et al [5] who follow similar methodology reporting all data as electricity. To a large extent their numbers are similar to those reported here with the exception of nuclear that is quoted to be 75. Weisbach report values for solar PV and wind that are “buffered” to include the energy cost of intermittency. This reduces the ERoEI for solar PV by about half and wind by a factor of 4. “Buffered” ERoEIs are therefore also included in Figure 6.

The inclusion of high altitude kite is based on a calculation provided by site sponsor KiteGen. I have checked the calculation and am satisfied that the ERoEI is potentially >>50. This will be the subject of another post. But suffice to say here that wind speed at altitude may be double that on the ground and power increases by the cube of wind speed. And the mass of the KiteGen structure is a small fraction of a large wind turbine. Hence it is theoretically straightforward to reach an ERoEI at altitude that is many multiples of the ERoEI of a wind turbine.

Figure 6 At altitude the wind speed may be double that on the ground. Accessing that kinetic energy resource provides potential for a 2 to 4 fold uplift in the power available for wind generation. This calculation does not include further uplift from higher capacity factor and reduced intermittency at altitude.

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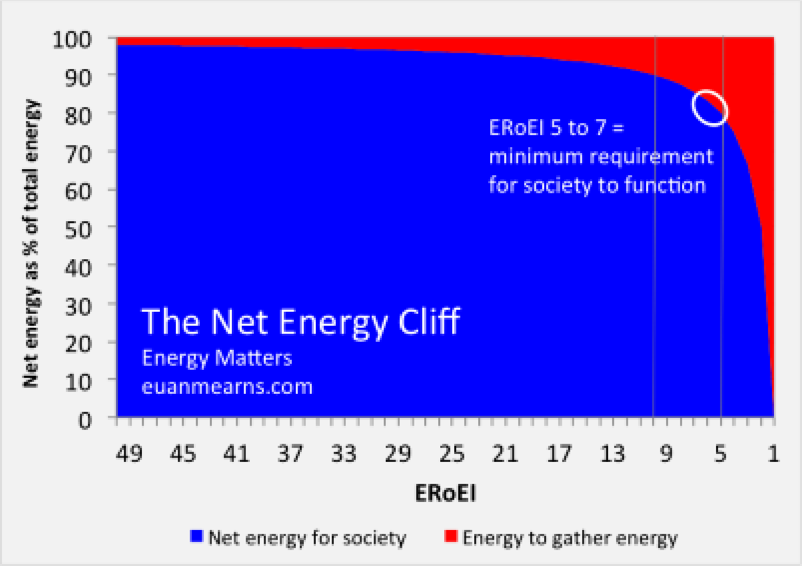
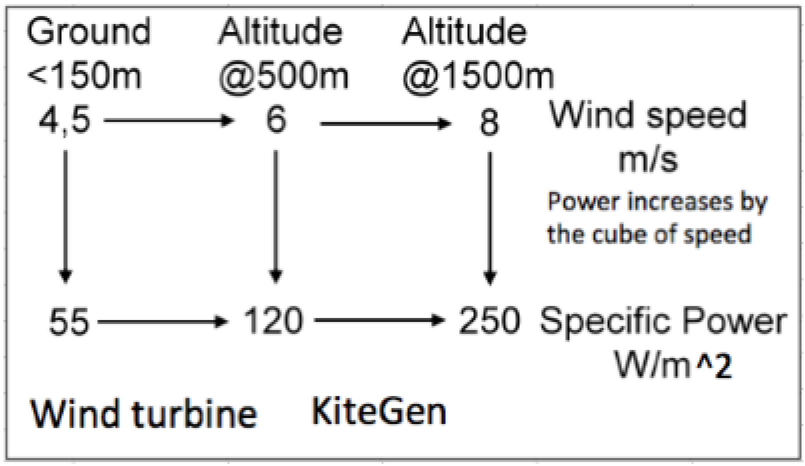


The key and fundamental observation from Figure 6 is that three energy sources potentially have ERoEI >> 50 making them vastly superior to all others using this metric. These are hydroelectric power, possibly nuclear power (depending upon whose numbers are believed) and possibly high altitude wind power once the technology matures.

These primary high ERoEI sources are followed by coal and natural gas which are the most viable and easily accessible energy sources for electricity today. And yet energy policies are dictating that coal be phased out. This will not matter for so long as natural gas remains plentiful at high ERoEI. The high ERoEI



group may also include nuclear power depending upon whose ERoEI numbers one believes.

Biofuels are already over the net energy cliff and should never have been pursued in the first place. Solar PV is at best marginal, at worst an energy sink.

There is a vast range in estimates for nuclear power from 5 to 75 [4, 5]and it is difficult to make sense of these numbers. Nuclear power either sits close to the cliff edge or is a high ERoEI low carbon saviour of humanity. Oil will not be used for electricity production and the fact it sits close to the cliff edge today in Eeq form does not matter too much since the energy quality of oil has a special status as an essential transport fuel and this will unlikely change much in the decades ahead.

Concluding thoughts

The concept of ERoEI is vital to understanding the human energy system. 50 years ago, our principal sources of energy – oil, gas and coal – had such high net energy return that no one need bother or worry about ERoEI. Vast amounts of net energy were simply available for all who had the level of technological development to build a power station and a transmission grid. It is part of human nature to “high grade” mineral deposits targeting the richest seams first. In economic terms these return the biggest profit and in energy terms when it comes to oil, gas and coal, they return the highest levels of net energy. An inevitable consequence of this aspect of human nature commonly known as greed is that we have already used up the highest ERoEI fossil fuel resources and as time passes the ERoEI of new resources is steadily falling. This translates to a higher price required to bring on that marginal barrel of oil.

At the present time, our energy web comprises a myriad of different resources. The legacy supergiants – Ghawar, Black Thunder and Urengoy et al – are still there in the mix supplemented by a vast range of lower ERoEI (more expensive) resources. The greatest risk to human society today is the notion that we can somehow replace high ERoEI fossil fuels with new renewable energies like solar PV and biofuels. These exist within the energy web because they are subsidised by the co-existing high ERoEI fossil fuels. The subsidy occurs at multiple levels from fossil fuels used to create the renewable devices and biofuels to fossil fuels providing the load balancing services. Fossil fuels provide the monetary wealth to pay the subsidies. Society is at great risk from Greens promoting the new renewable agenda to politicians and school children whilst ignoring the thermodynamic impossibility of current solar PV technology and biofuels ever being able to power human society unaided. The mass closure of coal fired power stations may prove to be fatal for many should blackouts occur.

Wind power, and in particular high altitude wind power, may be different although in the case of ground-based wind turbines care must be taken in moving offshore to ever larger devices that consume ever larger quantities of energy in their creation. And to be viable, ground based turbines must be able to prove they can deliver dispatchable power without subsidies.

It is proposed that money was invented as a means of exchange for the work energy does on our behalf. If we lived in a society with a single global currency (the EJ) and without taxes or subsidies, then money may represent a fair proxy for ERoEI although distortions would remain from the different efficiencies with which that money (EJ) was spent. However, in the real world, different currencies, interest rates, debts, taxes and subsidies exist that allow the thermodynamic rules of the energy world to be bent, albeit temporarily. We are at risk of exchanging gold for dirt.

Acknowledgement

The post was much improved by comments provided by Prof Charles Hall.

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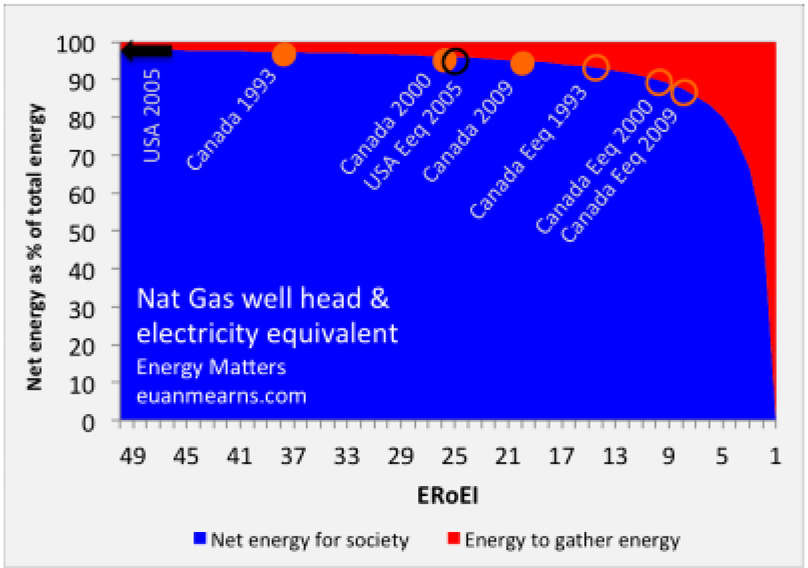
Energy Matters

Net Energy Trends

Euan Mearns

Energy Matters

27 May 2016



In writing Wednesday's post ERoEI for Beginners, I prepared a number of charts that were not used and these are presented here. Where it has been measured and according to the literature, the net energy of oil, natural gas and coal is falling everywhere. Surface mined US coal has one of the highest energy returns of any fuel and is substantially higher than deep mined Chinese coal. In electricity equivalent (Eeq) form, Chinese coal is marching towards the Net Energy Cliff edge while US coal remains far from it. The image shows part of a 50 km long queue of coal trucks in China.

Estimates of ERoEI for solar PV are all over the place (1 to 12) because different analysts set different system boundaries, the energy return is latitude and site specific and its possible that the literature based on historic deployed panels is not up to date with most recent advances.

Sugarcane ethanol in Brazil has ERoEI of 8 to 10 at the refinery gate which at face value seems OK [1]. But to be equitable with its FF cousins this needs to be reduced to 3 to 4 in Eeq form and is barely viable. Temperate latitude biofuels are not viable in liquid form at the refinery gate and converting them to Eeq cripples them completely. But I suppose burning them to make electricity is no less crazy than burning them in an internal combustion engine sat idle at traffic lights.

Most of the data in the following charts comes from Hall et al 2014 who summarise ERoEI research for a variety of fossil fuels and renewable energy flows (see table below) [2].

Oil and Gas

Note that this chart combines crude oil and natural gas and the data are for production which I assume to mean at the well head. Note that there is also a wide range of dates, which is part of the point of this chart.

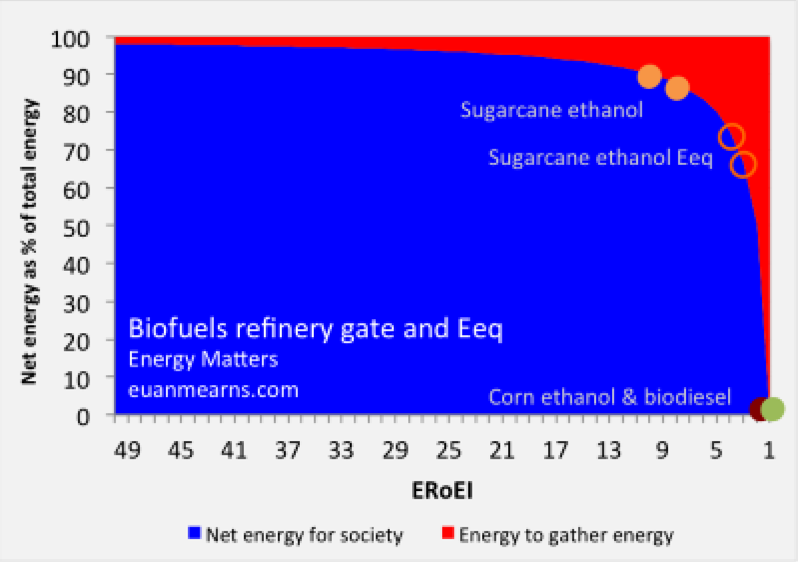
Note how the ERoEI of world oil and gas production is deemed to have fallen from 35 to 18 in just 7 years. I'm not sure this is credible. USA production is deemed to have fallen from 30 in 1970 to 11 in 2007. Canada from 65 in 1970 to 15 in 2010. It is very true that more men, machines and energy are being used to extract oil all over the world and this has pushed the cost of extraction higher as ERoEI has fallen. Or is it high price that has encouraged companies to expend more effort? And those thinking that the price has collapsed need to be aware that the cost of extraction has not collapsed and this translates to massive losses for producers. The trend of falling ERoEI is certainly real, the extent is open to debate. But if it continues, increasing amounts of our human resources are going to be spent on oil and gas production.

In my previous post ERoEI for Beginners I introduced the concept of electricity equivalence (Eeq). This is a first step towards trying to normalise different energy sources to a common datum. Crude oil at the well head is not much use directly to anyone. But it can be used to make electricity and in doing so roughly 62% of its energy will be lost as waste heat (BP convention). This normalisation enables direct comparison with renewables and nuclear, that have the advantage of producing electricity directly.

Following this convention, oil and gas production in the USA and China has already fallen off the net energy cliff while global production is getting close to it.

Natural Gas

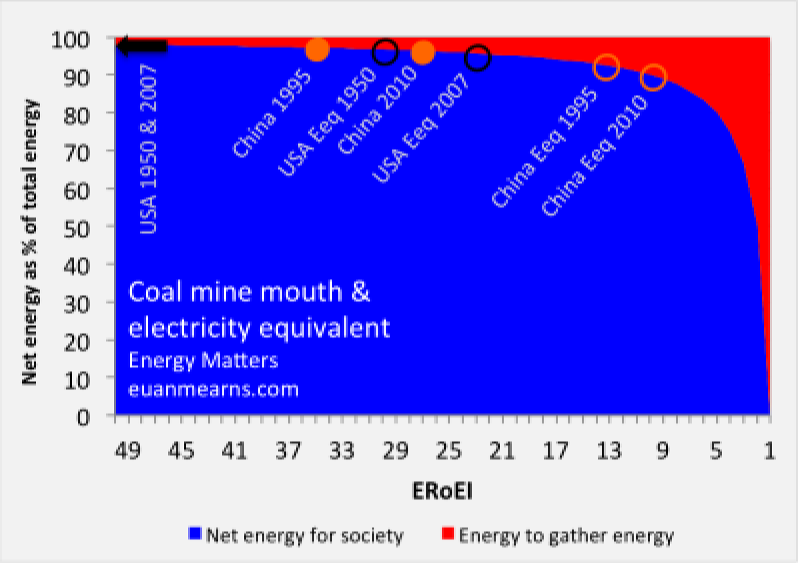
In 2005 (pre-fracking) US natural gas had high ERoEI of 67. Freise (2011) charts the decline in Canadian gas ERoEI from 38 in 1993, to 26 in 2000, to 20 in 2009. This march towards lower ERoEI in Canada is sending Canadian gas Eeq towards the net energy cliff edge. Large quantities of natural gas in Canada are used in tar sands extraction and upgrading. High ERoEI gas is being traded for liquid fuel that has ERoEI of about 3 (own calculation based on published Canadian statistics).



Coal

Hall et provide ERoEI data for the USA and China. US coal has very high ERoEI of 80 in 1950 and 60 in 2007. The fall is only slight and that is because mining methods have not changed very much. US coal is mainly surface mined from vast surface deposits in the Appalachians and Wyoming. By comparison, Chinese coal had ERoEI of 35 in 1995 and 27 in 2010. The lower ERoEI of Chinese coal to large extent reflects underground mining compared with surface mining in the USA. The Chinese need to apply vast effort to extract and transport coal to drive their economy.

The open circles show the electricity equivalent values. The mine mouth values are reduced by 0.38 and no deduction is made for transport. We see that US coal Eeq is probably one of the highest energy value sources we have but it is being forced out because of concern over CO2 emissions. Part of the problem here is that US coal is too easy to produce making it a fuel of first choice for exploitation. Chinese coal Eeq is getting closer to the Net Energy Cliff edge.



Renewable Electricity

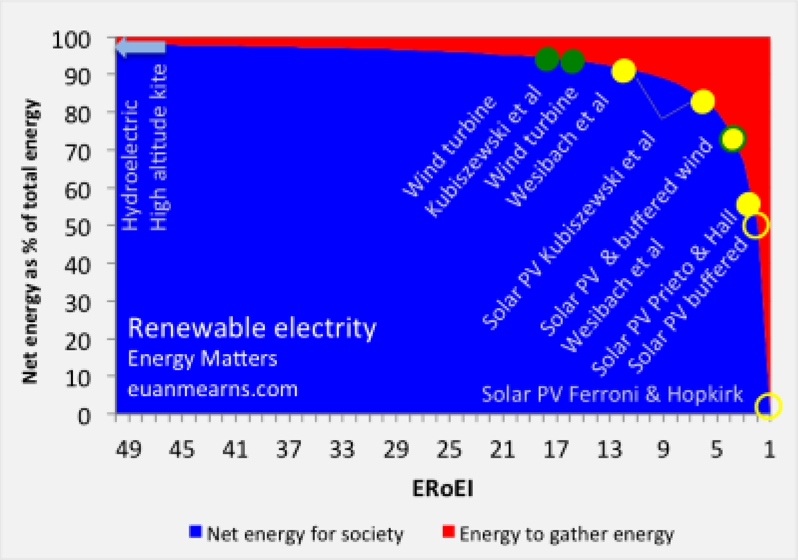
Hydroelectric power

There seems to be agreement that Hydro Electric power has high ERoEI. A large amount of energy is invested at the start in excavation, concrete and generating kit. But thereafter a dam may produce electricity for 100 years or more with little operation and maintenance energy costs. Although many dams today are getting fitted with new more efficient turbines, which means a new energy and economic investment.

High altitude wind

As explained in my earlier post, high altitude wind has potential to multiply the ERoEI of ground based wind turbines. The argument here is rather complex and will be explained in greater detail in a separate post. Suffice to say that the mass of the KiteGen, and hence energy embedded in the materials, is a fraction of that in a large turbine. This is specific to the design concept.

Wind turbines



The ERoEI of a wind turbine is site dependent. A good windy site will produce more energy over the life of a turbine in a calm site. The wind industry has tended to focus on sites with good wind resource and so site specific factors are less than for solar. A large number of studies places the primary ERoEI of wind turbines in the ballpark 15 to 20 and there doesn't seem to be too much disagreement on that.

The contentious issue for wind is treatment of intermittency. Is there an energy cost associated with that? Of course there is. Broadening the ERoEI boundary to create dispatchable power substantially reduces the ERoEI. At present this economic cost is not paid by the wind producers but is borne by others. Weisbach et al [3] reduce the primary ERoEI of wind by a factor of 4 to generate their buffered ERoEI assuming that pumped storage hydro is used. But they rightly note that using FF balancing services would have a lesser impact.

Solar Photovoltaics

With a range of ERoEI from 1 to 12, anarchy reigns in the PV ERoEI business. There are a number of issues at play here. The first is that different energy boundaries are being used. I personally favour a wide boundary that includes direct energy use, materials and labour. And for intermittent technologies a reasonable energy cost needs to be apportioned to mitigating that intermittency. The second is that solar PV is site specific. A sunny tropical site may yield three times the lifetime energy of a cloudy high latitude site. The third is that the efficiency of PV is improving all the time. Mixing these factors to varying degrees underpins the anarchy. But adding battery storage to a good tropics-based system is going to substantially reduce the ERoEI. Proponents of Solar PV seem set to continue to promote optimum performance without backup while others will observe that normal performance is sub-optimal and that in the real world the sun does not shine at night.

Liquid biofuels

Sugar cane ethanol is made in the Tropics where there is more abundant solar energy. And sugar cane employs a more efficient photosynthetic route than maize to manufacture carbohydrate more efficiently. No fossil fuel based fertiliser is required and the bagasse (left over organic cane waste) is combusted to make electricity in the refinery. These conditions combine to give sugar cane ethanol a viable ERoEI of 8 to 10 at the refinery gate [1]. Too bad about the disappearing forest.

I have tried to develop an equitable way of comparing different renewable and fossil fuel based energy sources by reducing all to electricity equivalent. And I'm afraid that sugar cane ethanol cannot escape that net. In Eeq form, sugar cane ethanol falls off the Net Energy Cliff.

The temperate latitude biofuels (corn ethanol and biodiesel) are really not worth discussing again.

Concluding thoughts

The energy debate continues to be partly driven by emotion and not by the laws of physics and needs of human society or nature.

My own opinion is that understanding ERoEI is vital to the continuance of industrial society as we know it. That does not mean projecting economic growth infinitely into the future but managing the energy and human resources and natural resources we have in a rational and responsible way. One that optimises benefits for humans and nature.

Understanding the intricacies of the human energy web is enormously complex and requires substantial resource to fully understand it. But it is not nearly as complex as understanding the climate system and I would argue that understanding our energy web is far more important. And so here is a challenge for the United Nations. Establish 10 working groups globally to study the human energy web, deliberately choosing ones with opposing outlooks at the outset (fossil fuel v nuclear v renewables v collapse) and challenge them to model the human energy web and to explore the multitude of outcomes.

And to then use that information to answer if asking Africa to skip over the fossil fuel stage of their energy development is beneficial to Africans?

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Energy Matters

Wind Power: the wick just ain't worth the candle.